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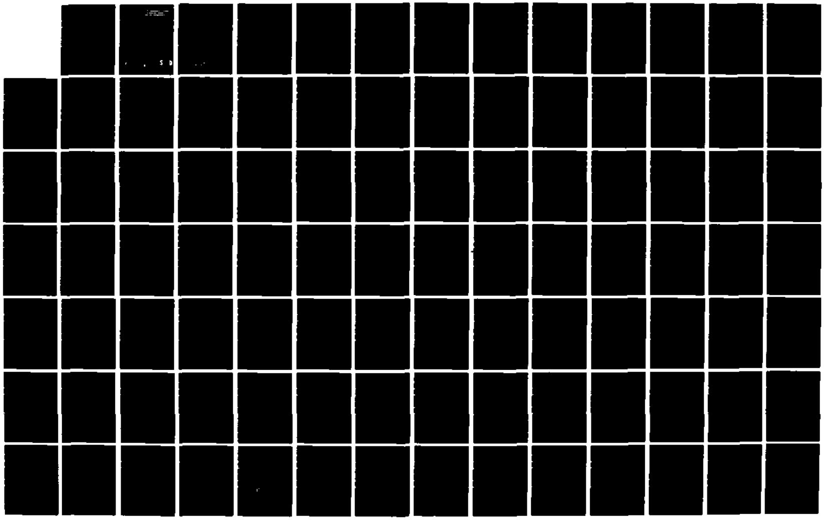

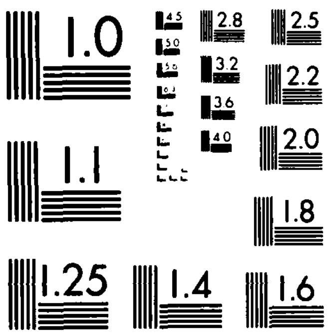
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Associate Administrator for
Development and Logistics
Washington, D.C. 20591

FAA Assessment of Satellite Concepts and Aviation Spectrum Requirements

February 1985

U.S. Department of Transportation
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*Richard F. Bock, Anthony Buige, Victor E. Foose, Raymond Johnson
Rudolph M. Kalafus, Siegbert B. Poritzky, David C. Scull, Melvin Zeltzer

16. Abstract

This report documents an FAA effort that identified aeronautical safety related air-ground services that might be provided in the future by satellite services, made estimates of L-band frequency spectrum for these services, and developed an approach and conditions for sharing satellite services with other users.

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The FAA Assessment of Satellite Concepts and Aviation Spectrum Requirements is based on the work, reported on herein, of an FAA Task Group which worked for several months in late 1984, and early 1985.

Richard F. Bock (FAA/ACT-200)	Rudolph M. Kalafus (TSC/DTS-52)
Anthony Buigo (FAA/AES-300)	Siegbert B. Poritzky (FAA/ADL-5) Chairman
Victor E. Foose (FAA/ADL-5)	David C. Scull (RSPA/DMA-26)
Raymond Johnson (FAA/AES-500)	Melvin Zeltser (MITRE/W-46)

PRECIS

Since near the beginning of radio, aviation has depended on high-integrity communications, surveillance, and navigation information, and its requirements of any new service are thus necessarily stringent. While aircraft numbers are relatively small--a few thousand airliners, a few tens of thousands military aircraft, a few hundred thousand general aviation aircraft—more than one and one-half million people per day fly, and depend on the best and safest system that communications technology can offer.

FAA and the aviation community have been studying the potential of satellite services for aviation since 1965. While satellite services have clear and obvious attractions, their high cost has up to now prevented implementation in the U.S. and the world's aviation system. Recent developments of technology and of commercial service offering indicate that these services are likely to become cost-effective.

In order to focus more clearly the future role of satellites in air traffic control, FAA analyzed satellite system concepts which might become acceptable to FAA and the aviation community, and developed such concepts to the point that estimates of required radio frequency spectrum might be deduced. In doing so, it was necessary to make a series of assumptions about prospective changes in technology, the future need for either new services or changes in current services, the expected number of participants in the system, and anticipated distributions of aircraft in representative areas.

FAA did not assume that all aviation services would, a priori, need to be satellite-based, but tried to forecast applications where satellites have unique capabilities to serve aviation effectively. In order to meet anticipated requirements, satellites are likely to become an important part of the aviation system.

FAA did not commission new studies by outside experts, but drew on previous studies and internal expertise available to it. The result is a preliminary assessment. Much additional work, system studies, and development will be required to bring these concepts to fruition.

FAA examined a series of potential satellite applications and selected concepts for which spectrum requirements could be identified. The concepts build on each other. In the first, it is assumed that a highly accurate, high-integrity, multi-purpose (not exclusively aviation) satellite navigation service would serve as the basis for all air navigation except Category II and Category III precision approach and landing, and that the navigation information will be of sufficient quality to serve also as the data source for an automatic dependent surveillance function, which would be the primary

surveillance service of the system. Communications will be predominantly satellite communications, heavily digital data, but with voice service retained for emergency and some routine party-line communications. It was postulated that certain communications, predominantly in high-density terminal areas, might be conducted most efficiently ground-to-air without using satellite relay, but that such communications should be conducted in the same band to permit the simplest practical avionics complement. Spectrum was set aside for this function.

In the second concept, it is assumed that automatic dependent surveillance using precision navigation information will not be found fully acceptable to the community, and, therefore, a cooperative independent surveillance system is added and spectrum set aside for it. Two alternative cooperative independent surveillance concepts are postulated—one, a space-based evolution of the Mode S Secondary Surveillance Radar System using a system of geosynchronous satellites; the other a synchronized satellite ranging system using a number of geostationary satellites and aircraft-derived altitude information.

As a third concept, it was further assumed that cooperative independent surveillance might not be acceptable, and spectrum was set aside for a noncooperative "space-based" system to perform the same function currently provided by primary radar. It was recognized that such a system lies far in the future and its viability is subject to question.

The cooperative independent surveillance system may require exclusive spectrum allocation for aviation, and the spectrum assigned is sized to meet projected aviation needs.

For communications, while the expected requirement is substantial, FAA did not find persuasive reasons why such services cannot be combined in acceptable ways with service to other users. While it is expected that a number of frequency allocations and assignments of channels (or bandwidth equivalent of channels) will be used and need to be assigned exclusively for aviation, sharing of satellite platforms and, in some instances, transponders or frequency channels may be possible if certain ground rules on primary versus secondary service, including instantaneous access, protection from interference, and priority are scrupulously adhered to. No compelling reasons were found why such communication services need to be Government-operated as long as the requirements of the responsible government air traffic service authorities are met. Similarly, the synchronized-ranging type of cooperative independent surveillance could be part of a commercial service, given adequate guarantees of primary service, integrity, and availability.

It is recognized that satellite sharing possibilities could be beneficial to aviation, especially during the introduction of, and transition to, a satellite communications service, because of the possibility of sharing the high cost of space segment resources. However, the projected aviation requirement would more than fully utilize spectrum equivalent to the bands now allocated to the aeronautical mobile satellite (R) service and the ability to meet that requirement must not be foreclosed. During the transition period,

it is expected that the bands will not be utilized fully by the aeronautical safety services. Because the aeronautical requirement is likely eventually to require all of the spectrum currently allocated, it is considered appropriate to maintain the aeronautical mobile satellite (R) service as the <u>only</u> primary service in the currently allocated bands, with other services which can meet the ground rules laid out herein designated as secondary. Such a designation would assure clear precedence of aeronautical safety services.

In determining this requirement, FAA assumed that an evolution of satellite technology can be expected in which progressively more capability will be practically achieved, thereby easing the transition into extensive aviation satellite use.

While FAA considered predominantly safety services, it recognized the continuing requirement for operational control communications, and included a spectrum segment for such communications. This requirement was furnished by ATA/ARINC, and is included as given. FAA recognized the potential for aeronautical public correspondence, but agreed that it is not an aeronautical safety service, and therefore no spectrum requirement is specified herein.*

FAA chose to size the system under the assumption that all aircraft in the projected time frame would require services. This approach, which results in a larger spectrum requirement than would be required if only a portion of the aircraft were assumed to require services, is offset by other assumptions--which may be considered optimistic by some--concerning the potential for frequency reuse, relatively high-efficiency modulation techniques, etc., which tend to reduce the spectrum requirement.

FAA concluded that the availability of L-band spectrum in paired channel assignments would be a requirement, and that spectrum amounting to more than the currently allocated 1545-1559/1646.5-1660.5 MHz aeronautical mobile satellite (R) bands is likely to be required by the year 2010 to support aeronautical satellite and related services. The summary requirement results in a need for 14.5 MHz for the downlink (satellite to aircraft) and 15.95 MHz for the uplink (aircraft to satellite), with an additional 20 MHz (probably of the 1559-1610 MHz radionavigation satellite band) reserved for the introduction of noncooperative independent surveillance using a radionavigation satellite band.

*FAA concerned itself with radio services which are classified by FCC and NTIA as either shared government and non-government <u>or</u> exclusively government, and did not address services such as public correspondence which are exclusively non-government.

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Report of the FAA Task Group on
Satellite Concepts and Spectrum Requirements

1. INTRODUCTION AND QUALIFICATIONS

The competition for the frequency spectrum which is currently allocated nationally and internationally to the Aeronautical Mobile Satellite (R) Service and other aeronautical radio services is growing increasingly intense, and there is a risk that spectrum required to serve aeronautical functions in the future via satellite or terrestrial services in these frequency bands may be lost if the aviation community does not state clearly its needs for the future.

A number of activities are underway to establish those future aviation needs. Among them are the ICAO Future Air Navigation Systems (FANS) Committee, which is charged with defining aviation's needs and the technology to serve those needs for the next 25 years; the Radio Technical Commission for Aeronautics Special Committee 155, User Requirements for Future Communications, Navigation and Surveillance Systems, Including Space Technology Applications; as well as a number of activities in other countries. Literally hundreds of concepts for aeronautical use of satellite services have been offered; yet none have been accepted by the aviation community, either because the need has not been clear or because the costs have been either unknown or considered too high to warrant implementation. However, there is little doubt in the minds of most aviation experts that satellite applications are highly attractive for aviation use and that viable, cost-effective applications and service arrangements will be established.

In order to help lay out prospective concepts for such satellite services and to create rational estimates for spectrum requirements, a small group of technical experts was assembled by FAA to develop one or more satellite system concepts which might become acceptable to FAA and the aviation community, and to develop such concepts to the point where estimates of required frequency spectrum can be deduced. In doing so, it has been necessary to make a series of assumptions about prospective changes in technology, the future need for either new services or changes in current services, the expected number of participants in the system, and the anticipated distributions of aircraft in representative areas ranging from high-density traffic environments, to oceanic, to low-density operations in developing parts of the world. It was

necessary to postulate a number of technical parameters, such as the level of achievable frequency reuse in satellite systems through use of spot beams, and achievable minimum channel spacings for voice and digital data communications. Any analysis of this kind is, by its nature, presumptuous because it predicts the future. But without such predictions, realistically and conservatively applied, no result is achievable. In doing its work, the group attempted to avoid assertions which would limit design flexibility for the future or restrict application of technologies anticipated to grow. But there is no doubt that the judgment of others and time may lead to changes in these conclusions. The result is a preliminary assessment. Much additional work, system studies, and development will be required to bring these concepts to fruition.

In conducting its work, the group did not assume that all aviation services would a priori need to be satellite based, but tried to forecast applications and services where satellites have unique capabilities to serve aviation effectively. The group was aware of many studies, concepts, and techniques conducted by DOT/FAA and its contractors, as well as NASA and DOD, over the past 20 years. It was aware of many current proposals and the state of current technology. It was also aware that technologies are changing rapidly and that the nature of the aviation industry can be expected to change.

While the group did not commission new studies by outside experts, but, instead, drew on previous studies and internal expertise available to it, it believes that its conclusions have substance and deserve consideration.

2. SUMMARY FINDINGS

Integration of Functions

The group considered at length the benefits and liabilities of integrating the classic functions of communications, navigation, and surveillance. It agreed on a number of basic ground rules, the most important of which is that no system will be acceptable if failure of a single element could deprive the system simultaneously of both navigation and surveillance.

The group agreed further that the traditional philosophy of separation of functions is sound, and that backup should be available, but that redundancy of similar systems can serve in many instances to protect against single-element failures.

Navigation

For navigation, the horizontal position can be obtained from any suitable area navigation system still in use in 2010. Because of the major benefits it offers, the group believes that a satellite navigation system will eventually replace most ground-based navigation systems for en route operations and for nonprecision approaches. GPS, or a logical technical evolution of it, is likely to be that navigation system.* Further, the group assumed that the full-accuracy capability of GPS will become available to civil users, and that the current problems in achieving coverage, reliability, and integrity will be resolved by one of several means. Should this come true, it may become practical to achieve precision approach operations to minimums of 200 feet and 1/2 mile (current Category I) using that satellite navigation system. It is assumed that GPS will not be adequate for full (CAT II and CAT III) precision approach and landing services. It is anticipated that the Microwave Landing System (MLS) will provide that service.

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*In the report, "GPS," unless otherwise stated, should be interpreted as the navigation system evolving from the present GPS design.

FOR CONCEPT 2 (A or B) -- ATC FUNCTIONS

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
*Space Communications (including automatic dependent surveillance reporting once every 10 seconds)			
Digital	3.3 MHz	2.5 MHz	
Voice	1.2 MHz	1.2 MHz	
**Terrestrial (Ground-to-Air) Non-Satellite Voice & Data (including 1 MHz buffer on downlink)	2.4 MHz	1.65 MHz	
*Space Communications Adjacent geographic area Services (where frequency reuse is not possible)	1.0 MHz	1.0 MHZ	
**Space Cooperative Independent Surveillance (System similar to Mode S surveillance function, with independent altitude check)	1.0 MHz	4.0 MHz	
***Space Cooperative Independent Surveillance (Synchronized, range-based surveillance requiring aircraft altimeter data)	1.0 MHz	4.0 MHz	
	8.9 MHz	10.35 MHz	

*These frequencies can be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section [illegible] are fully satisfied.

**Not sharable

***Possibly not sharable

FOR CONCEPT 1 — ATC FUNCTIONS

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
*Space Communications (including automatic dependent surveillance reporting)			
Digital	3.3 MHz	4.8 MHz	
Voice	1.2 MHz	1.2 MHz	
**Terrestrial (Ground-to-Air) Non-Satellite Voice & Data (including 1 MHz buffer on downlink)	2.4 MHz	1.65 MHz	
*Space Communications Adjacent geographic area Services (where frequency reuse is not possible)	1.0 MHz	1.0 MHZ	
	7.9 MHz	8.65 MHz	

*These frequencies can be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 are fully satisfied.

**Not sharable

The growth of technology may make one or another transmission method--FDM, spread-spectrum techniques, TDM systems, etc.--more attractive than others for some functions. The group believes that the projections made here will be applicable for a variety of anticipated information transfer techniques.

The group believes that these projections may have some value in considering the worldwide situation for the future. In the calculations, the projected traffic situation anticipated for the U.S. was used, but it recognized that adjacent or related areas may have lesser demands and may therefore use less ambitious space systems. Spectrum is identified to permit such operations.

L-BAND SPECTRUM REQUIREMENTS PROJECTION

Assumptions:

1. The system has been sized to provide services to all aircraft.

2. Most ATC functions are assumed to use digital communications, but voice capability must be available for nonroutine, emergency, and some specific functions (limited party line).

3. To achieve minimum aircraft equipment complement, all ATC and operational control communications, including terrestrial ground-to-air (non-satellite) services are assumed to be at L-band.

4. Earth station-satellite spectrum requirements are not included.

5. Frequency spectrum requirements for GPS are not included in these calculations.

6. While design studies have not been done, there is concern that the disparity in power level between terrestrial-to-aircraft and spacecraft-to-aircraft transmission may cause technical difficulties. Therefore, a buffer requiring an additional 1 MHz of spectrum is shown in the spectrum requirement.

which could eventually permit the elimination of a variety of current systems, such as VOR/DME; Primary Radar, and possibly Secondary Radar in all but high-density terminal areas; to substitute L-band voice and data communications for existing VHF and HF communications (except possibly in polar regions); and eventual removal of other navigation systems, such as Loran-C, OMEGA, etc.

In making these postulations, the group did not establish the timing for withdrawal of such systems, nor did it decide whether they would indeed be removed. The group recognized the problems of transition and considered that the timing of withdrawal of currently existing systems would depend on the implementation of the new systems, the perceived need for retention by various elements of the aviation community, the willingness of governments and users to continue financing eventually redundant systems, and a variety of other factors.

The purpose here is to identify spectrum requirements for prospective future systems without assuming or commenting on the timing or need for withdrawal of current systems.

SPECTRUM REQUIREMENTS

Considering all the foregoing requirements, the following is the task group's projection of the spectrum anticipated to be required to support aviation services to the year 2010. This projection assumes the use of modern technology to achieve spectrum efficiency and high spectrum utilization. It is important to note that while the group assumed that all aircraft would utilize the system fully (requiring more spectrum than if only a portion of the aircraft participated), fairly ambitious assumptions were made about technological progress in frequency reuse, spacecraft multiple beam technology, utilization efficiency, etc. (which tend to reduce the spectrum requirement).

The task group considered this concept important because of the high level of independence it provides for the surveillance function and the independent altitude crosscheck it provides.

The group also considered another concept, Concept 2B, using synchronized ranging via several geostationary satellites and altitude input from the aircraft. This concept is significantly less independent relative to Concept 2A, but has merit since it requires fewer satellites and potentially allows the use of commercial satellite services to satisfy this function.

Concept 3--Noncooperative Independent Surveillance as a System Requirement

Concept 3 makes the same assumptions as those for Concept 2, except it postulates further that cooperative independent surveillance will not be fully acceptable to governments and users, and that a primary surveillance system which does not require cooperation by the aircraft will continue to be a requirement. In this concept, ground-based radar will continue to be required, but space-based radars will be needed for some operations, such as over oceans, for operations near the ground, and possibly to meet other specialized requirements. In addition to the spectrum required for Concept 2, additional spectrum will be required for the space-based radar. However, because only one-way transmissions are required to support this application, it will not be performed in the paired 1545-1559 MHz and 1646.5 to 1660.5 MHz bands.

It is not considered that space-based primary radar for civil applications is a near-term possibility; its cost and complexity are likely to be unacceptable for decades after its capabilities are demonstrated. Nonetheless, the attractions of such a capability should not be foreclosed, and spectrum, possibly somewhere in a radionavigation satellite band, should be earmarked for such a potential.

Removal of Existing Systems

The problem of transition and the eventual decommissioning and withdrawal of systems was considered briefly. The group chose to define system concepts

Commercial satellite services are likely to be the most attractive way of meeting these communications and dependent surveillance requirements, assuming stringent adherence to ground rules set out herein. In this concept, there is no requirement for independent surveillance, either primary (non-cooperative) or cooperative.* Although it is recognized that primary radar may be retained in high-density terminal areas, no new spectrum is anticipated to be needed for this purpose. Broad carriage of independent collision avoidance systems continues to be assumed.

Concept 2--Cooperative Independent Surveillance as the Primary Surveillance Source

Concept 1 assumes the integrity and reliability of the navigation/communications system to be so high that it can serve safely as the medium for automatic dependent surveillance and navigation everywhere, with appropriate built-in redundancy and failure protection to assure that the possibility of common-mode failures is so low as to be negligible. In Concept 2, it is assumed that governments and the aviation community will not agree that automatic dependent surveillance can be the primary surveillance service everywhere. Therefore, an additional cooperative independent surveillance service requiring sp[illegible]ed. Two ways of [illegible] were considered. [illegible] assumes that the Mode S surveillance system and its data link will remain in use for a long period, but that a space-based cooperative independent surveillance system (transponder required in the aircraft), using most of the principles of the earth-based Mode S, will come into being, utilizing the L-band aeronautical satellite spectrum. This system may use a number of common avionics elements with the ground-based Mode S, but the space element will serve a surveillance function only; i.e., it will transmit identity and limited additional information in response to interrogations. Two-way data link functions will utilize the communications [illegible] as in Concept 1.

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*However, provision may be made to enable ATC to obtain an independent single line-of-position using a range measurement with the communications channel (in conjunction with time synchronization) and altitude from the altimeter.

separation standards will be implemented based on minimum navigation performance standards suited to the applications. Other suitable navigation systems may be available and used. The integrity of other systems must be proven to be as high as the basic service if this concept is to be viable.)

Three-dimensional information will be available, along with a standard system time service.

Barometric altimetry will remain an important element in the system, but the geocentric altitude available from the enhanced GPS will serve as a crosscheck on barometric altimetry systems and may serve as a primary service in future collision avoidance system concepts.

The GPS signal will be of sufficient integrity to serve as the source for automatic dependent surveillance, in which navigation position information is transmitted to the ground either directly or via satellite relay, to serve as the primary surveillance system for all airspace. It may also find use as a data source for collision avoidance systems.

In this concept, a satellite communications relay will be used extensively to transmit automatic dependent surveillance position information, along with additional information, as required and available, on aircraft state, intent, winds aloft, etc. The communications services between aircraft and the ground system will utilize satellite relay extensively in over-ocean areas, at low altitude in low-density and high-density airspace, and for other purposes.

It is assumed that in high-density areas, the bulk of communications may be such that a direct ground-to-aircraft and aircraft-to-ground communications system may be preferable to a satellite-based communications system. For this purpose, in order to permit use of common avionics, spectrum in the L-band will need to be identified for such a terrestrial-based communications system as well. Aircraft operators will continue to require spectrum for operational control and administrative communications. Much of the communications will be digital data link, but a continued voice capability is needed and provided.

While most current navigation systems will not have been phased out at the completion of NAS Plan implementation, military use of GPS will be widespread and civil users will have begun implementation and use of GPS—first as a supplementary and later as a "sole-means" navigation system, in a situation in which minimum navigation performance standards will be widely implemented and equipment choices left to the user.

New Concepts—2010 Time Period

It is in the context of the implemented NAS Plan system that the task group considered concepts for satellite services. The following are the concepts selected by the task group. More detailed descriptions of the concepts and the spectrum requirements for execution of these concepts are given in Sections 7 and 8. For all of the concepts, the group postulated that new communications, navigation, and surveillance systems should be capable of providing their services anywhere on the earth's surface and from the surface to 70,000+ feet. They must be practically implementable where they are needed, without penalizing low-activity areas to serve high-density areas. Navigation services are likely to be implemented globally; surveillance and communications regionally applied and controlled.

Concept 1—Automatic Dependent Surveillance as the Primary Surveillance Source

Concept 1 assumes that a satellite navigation system will prove to be a highly reliable, high integrity, and high-accuracy system. The accuracy and integrity of the system will be such that it can serve all navigation functions with essentially instantaneous failure warning in oceanic, en route, and terminal operations, providing information adequate to support 200 feet and 1/2 mile (CAT I) minima. GPS is likely to be that system. It is assumed that the full-accuracy capability of the system will be available to all users. It is also assumed that the satellite navigation system, if GPS, will have evolved and improved to become the prime and "sole-means" navigation system for many operators. (GPS, or an evolution of it, is assumed here to be the basic service provided by the government/s. Services will be provided and

motivation, the provision of a system which permits aircraft to perform their desired missions in the safest, most efficient, and least constrained way. New sensor systems will be judged on whether they permit aircraft operations which are safer, more flexible, more economical, or more efficient than competing alternatives.

The Mid-1990's Baseline

In considering concepts for the future, the task group assumed that the U.S. National Airspace System Plan will be successfully executed by the mid-1990's and the modernized system will be in place. Area Control Facilities in which Center functions and approach control functions are beneficially combined will be in wide use. A high level of system automation will have been achieved. The human controller, still an integral part of the system, will be more a system manager than a moment-to-moment control executor. There will be wide use of digital ground-air-ground communications, but voice will be available for nonroutine and emergency communications. Extensive use will be made of Mode S and its data link for safety communications, and a variety of safety- and efficiency-related data will be exchanged by the Mode S data link. Different data links may be in use by air operators for company and other functions, and it is anticipated that an "open system architecture" will be implemented. Minimum performance standards for navigation will be in wide use, and a limited number of different area navigation systems will be in use to meet those standards--VOR/DME, DME/DME, Loran-C, OMEGA, INS, and GPS. MLS will have replaced ILS in most, if not all, applications. Primary radar will still be in the system, particularly in terminal areas, but possibly for other uses as well. A major FAA data interchange network, along with modern voice switching and control systems will be in place, designed to take advantage of a variety of communications carriers, both FAA-owned and commercial--possibly satellite--chosen on the basis of technical capability and economic competition.

There will be wide use of independent collision avoidance systems which will serve in both domestic and over-ocean applications.

GPS. The key requirement is for a uniform and standard system of ground/3D reference coordinates and a clear statement of minimum performance requirements to which all users agree to adhere.

In the communications and surveillance areas, there is an aviation requirement that there be sufficient uniformity in satellite services, technical standards, and protocols that the same avionics systems can be used worldwide and that the need to carry unnecessarily duplicative systems be avoided.

FUTURE SYSTEM CONCEPTS

The task group considered technologies for future aviation communications, navigation, and surveillance services which are likely to require use of the aeronautical satellite bands. It agreed on several concepts which have high potential for implementation and use, and for which spectrum needs to be identified.

The group did not assume that all aeronautical services would need to be satellite-based, but attempted to select services with a high likelihood of implementation and beneficial use.

The Nature of the Air Traffic Management System

The air traffic management system will continue to be centrally managed and ground-based, although there will continue to be much airspace in which few, if any, controls are imposed.

In considering the concepts, the group agreed that the basic processes of air traffic control are not likely to be impacted in major ways by the kind of communications, navigation, and surveillance systems provided. While the character of such systems will influence the air traffic separation process, impact achievable separation standards, and have potentially major impact on efficiency and cost of the services, the guiding requirement is that the communication, navigation, and surveillance services have, as their basic

Communications Spectrum Sharing

The group discussed and studied the benefits and liabilities of sharing aeronautical communications with other services. Such sharing can be accomplished in a variety of ways, ranging from the sharing of satellite platforms to assignment of exclusive channels (or their future equivalent) for aeronautical mobile safety communications, to sharing individual communications channels with other services.

The group established certain ground rules on sharing. No basic reason was found to indicate that sharing of satellites, some frequency bands, and—with specific safeguards—channels, is impractical, assuming that protection is adequate. In summary, it concluded that the aviation safety service requires, in radio frequency engineering terms, primary allocation status to ensure against jeopardy to life and property. Other radio services would enjoy secondary allocation status. While, in practical terms, this does not place the secondary service at a significant disadvantage since the national and international frequency authorities will engineer frequency assignments so as to preclude interference to the maximum extent, it guarantees that, should the primary service be jeopardized in either an allocation or assignment matter, there will be a clear order of precedence.

It is likely that the need for such separate, protected communications system channels is likely to grow from an initial requirement to a larger requirement, and that access to additional channels as they are needed must be guaranteed. Given scrupulous adherence to the ground rules, there is no reason why such services must be Government-owned or operated.

World-Wide Uniformity

In considering requirements for services and the technological means of serving such needs, the group recognized the importance of uniformity of such services over the world. GPS is worldwide by its nature, but users may find it appropriate to use other navigation systems instead of, or in addition to,

Communications

By far the most important application of satellite technology is in the provision of communications services. In consideration of the concepts described herein--one in which automatic dependent surveillance is the primary surveillance system, and the others in which it is assumed that no form of dependent surveillance alone will be acceptable, the quality of communication services must be of the highest order.

It was agreed that while much communications will be done by digital means on data links, voice services must be available at all times, for emergency and some routine party-line communications.

It was agreed that while much of the air/ground communication is likely to be satellite based, some communication services, especially those for terminal area operations, may be better conducted using ground communications facilities. It was agreed that it may come to be advantageous to utilize the same avionics and, therefore, the same L-band frequency spectrum to provide both for satellite-based communications and ground-based air/ground communications, perhaps eventually replacing the current VHF communications spectrum.

While the group did not consider the provision of spectrum for public correspondence to be a part of the aeronautical safety spectrum requirement, it recognized the need of commercial operators for spectrum for operational control communications and administrative communications. For reasons of aircraft equipment economy, such spectrum should be integral or contiguous with other communication spectrum needs. The group asked the airline industry to estimate their needs. The airline industry has indicated a requirement for 5.6 MHz for operational control and administrative communications for the future. Appendix A describes the ARINC/ATA view.

The concept of automatic dependent surveillance is also attractive because it permits both aircraft and the provider of the air traffic services to utilize the same reference information It has the disadvantage that a failure or an unannunciated error might affect both the crew's information and the surveillance service.

o <u>Cooperative Independent Surveillance</u>

It is FAA's current policy to provide and utilize a primary surveillance system, i.e., primary radar, as well as Secondary Surveillance Radar (the Air Traffic Control Radar Beacon System, evolving to use of Mode S and its data link). The expected high quality of the GPS-based position data makes it a logical primary source for supporting an automatic dependent surveillance function, not only over oceans but also over land. While it is agreed that such automatic dependent surveillance is likely to become a primary system, the group believed that there will continue to be a need for independent surveillance, particularly in high-density congested terminal airspace.

Because of uncertainty about automatic dependent surveillance, and recognizing FAA's current policy, the group believed that spectrum must be retained for a prospective satellite-based cooperative independent surveillance system.

o <u>Independent (Non-Cooperative) Surveillance</u>

The group considered further that a prospective long-term requirement for a primary (non-cooperative) surveillance cannot be ignored. Since the possibility exists for viable space-based independent surveillance, it considers spectrum must be retained for such a possibility. However, this spectrum need not be reserved in the 1545-1559 MHz and 1646.5-1660.5 MHz bands, but would more likely be located in the 1585-1610 MHz band.

While barometric altimetry is likely to continue as an integral part of the aviation system, altimetry information derived from the satellite navigation system is likely to become an important adjunct and crosscheck. It may also come to serve as the primary data source for vertical separation in the en route environment and, although geocentrically-based, may come to serve as an altitude source for collision avoidance systems.

No additional spectrum beyond that currently allocated to GPS service will be required to support these navigation functions.

The group felt that broad user implementation of high-accuracy, high-integrity satellite navigation service could serve as a position information source for a future independent airborne collision avoidance system, and could serve as a basis for a widely implemented automatic dependent surveillance system, both over oceans and over land.

Surveillance

- Automatic Dependent Surveillance

  The concept of automatic dependent surveillance* as a primary surveillance system is attractive because it has the potential of simplifying the required avionics complement in aircraft and the ground facilities required for ground-based cooperative independent surveillance. It assumes that the position information derived from the navigation system and transmitted to the ground is of high accuracy and integrity, with essentially instantaneous failure warning. It further assumes that the position data transmitted to the ground for surveillance purposes is essentially raw information, only minimally processed in the aircraft, and without any modification by the crew.

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*Automatic dependent surveillance assumes a dependence on aircraft-derived navigation data, and is defined as the automatic readout of navigation data and transmission to and presentation to the air traffic controller without human intervention.

FOR CONCEPT 3 -- ATC FUNCTIONS

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
as for Concept 2	8.9 MHz	10.35 MHz	
plus			
Space Radar (noncooperative surveillance)			20 MHz*
	8.9 MHz	10.35 MHz	20 MHZ

*Spectrum for this function expected to utilize a radionavigation satellite band between 1585 and 1610 MHz.

SPECTRUM REQUIREMENT FOR OPERATIONAL CONTROL FUNCTIONS -- ALL CONCEPTS

(provided by ARINC/ATA on behalf of scheduled airlines)

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
Space Communications (Operational Control)	5.6 MHz	5.6 MHz	

SUMMARY — SPECTRUM REQUIREMENT FOR MOST DEMANDING CONCEPT

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
*Space Communications (including automatic dependent surveillance reporting once every 10 seconds)			
Digital	3.3 MHz	2.5 MHz	
Voice	1.2 MHz	1.2 MHz	
**Terrestrial (Ground-to-Air) Non-Satellite Voice & Data (including 1 MHz buffer on downlink)	2.4 MHz	1.65 MHz	
*Space Communications Adjacent geographic area Services (where frequency reuse is not possible)	1.0 MHz	1.0 MHZ	
***Space Cooperative Independent Surveillance	1.0 MHz	4.0 MHz	
Space Radar (noncooperative surveillance)			20 MHz****
Space Communications (Operational Control)	5.6 MHz	5.6 MHz	
	14.5 MHz	15.95 MHz	20 MHz

*These frequencies can be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 are fully satisfied.

**Not sharable

***Not sharable if space-based system similar to Mode S is chosen. Possibly not sharable if synchronized, range-based system is used.

****Spectrum for this function expected to utilize a radionavigation satellite band between 1585 and 1610 MHz.

3. The Scope, Ground Rules, and Prospective Services Related to the Task Group's Work.

3.1 Scope

The year 2010 was selected as the future year for the purpose of investigating meaningful future ATC system concepts and operational arrangements, and for estimating frequency spectrum needs for ATC services. Airline operational control and administrative communications, recognized as needed, were not estimated as part of this exercise. Instead, information provided by ATA/ARINC is included in Section 8.

The development of potential future requirements for a limited number of representative world areas was estimated to be sufficient to bound global spectrum needs, assuming that at least rudimentary frequency reuse would be available to service other areas of the world, and that similar service needs were to be expected. The areas chosen were North America, including the U.S., Canada, Mexico, and the Caribbean; South America; the Atlantic Ocean area; and the Pacific Ocean area.

The need for services, including communications, navigation, surveillance (and independent collision avoidance), were considered in the context of expected levels of future traffic. Consideration was given to evolving services or the foreseen need for service levels not presently provided, such as significant levels of data link communications to provide visual weather information in the cockpit.

3.2 Ground Rules

3.2.1 Basic Study Considerations

While spectrum requirements of present ATC system elements must, of course, be protected for a number of years to come, the group agreed to estimate the amount of spectrum that might be needed to satisfy future aviation safety system requirements under several different concepts.

The group recognized that about 75 MHz of L-band aeronautical spectrum was potentially available for future services. This spectrum includes the two 14 MHz segments planned for aircraft-to-spacecraft and spacecraft-to-aircraft communications with allowance for suitable diplexer arrangements compatible with adjacent maritime spectrum allocations.

3.2.2 ATC Functional Interrelationship and System Operational Ground Rules Assumed

1. In the ideal situation, excluding any consideration of avionics complements, it is desirable to have separate communication, navigation, and surveillance functions.

2. Combining any of the two functions entirely will require parallel or dissimilar redundancy in the avionics complement of most aircraft operating in Instrument Meteorological Conditions (IMC).

3. A system concept in which a single system element failure can simultaneously eliminate both the capability for cockpit navigation and ATC surveillance is not acceptable.

4. Combining all three functions may result in a safe system if sufficient redundancy is provided. However, this would require significant redundancy in the ground and/or space system elements, as well as aircraft avionics. The costs for this redundancy and related services (e.g., increased communications) are unknown.

5. New surveillance/communication system operational concepts should be judged with regard to their capability to impact a relatively low number of users if a system failure occurs.

3.3 Prospective Services

3.3.1 Navigation Services

Satellite navigation is likely to be the primary world-wide horizontal navigation service for the future. A GPS-based system is the likely candidate for this service, and GPS is likely to evolve to become technologically simpler and more applicable to civil needs. It is assumed that this GPS-based system will be a stand-alone system, not dependent on other aircraft systems for its successful operation. Future availability of increased accuracy to the civil community from GPS is assumed. This may include the availability of useful vertical position information; vertical guidance information will be required if GPS is to be used to support landing operations with operating minimums to 200 feet and 1/2 mile (current CAT I). MLS will be used to support precision landing services. There is at present no foreseen need for additional frequency spectrum to support future navigation services.

However, the present 18+3 GPS satellite constellation does not have sufficient reliability or integrity to satisfy civil aviation requirements for a "sole means" navigation system. To meet civil requirements for a sole means navigation system, the present constellation needs to be augmented by adding more satellites (e.g., 24 satellites + spares), or adding several geostationary satellites with GPS signal transmission capabilities (note: such geostationary satellites [illegible] the capability to provide communications in addition to navigation signals). Either GPS geostationary satellites or communication satellites are anticipated to be needed to send GPS health messages to system users. A differential GPS operational scheme, with local ground reference stations to monitor system health and provide increased accuracy by transmitting information to aircraft, is also an option to be considered for the future.

In developing the concepts to be assessed in terms of spectrum requirements, the task group examined several navigation system concepts. It was decided to concentrate on systems which can meet the ground rules concerning system fail-operational capability, as well as high accuracy worldwide. It

concluded that systems of nongeostationary satellites, optimally placed, were the most likely to find acceptance and use. The task group also considered the concept of "dependent navigation," but chose not to select it for the following reasons: A significant satellite constellation would be required to achieve services of the quality to be expected of an evolved GPS, i.e., high accuracy, vertical information, high reliability, and adequate signal integrity. The sequential use of a minimum of four satellite paths (aircraft to satellite to earth to satellite to aircraft) would be required to provide navigation information to the aircraft. Position report lags of 0.5 seconds for geosynchronous-altitude satellites (neglecting processing delays) must be expected, and such lags would not support CAT I instrument approach operations.

3.3.2 Surveillance Services

A highly reliable, high-integrity surveillance function must be achievable, and applied as appropriate, in any airspace (ground to 70,000 feet): (1) to effect adequate protection from blunders, ATC loop errors, and other human factor related errors while operating with the most efficient separation minima possible, and (2) to effect efficient air traffic services.

A surveillance position update rate of greater than once in 4 seconds for terminal area and other high traffic density operations is anticipated to be needed. For this analysis, a maximum rate of once each second has been estimated to be a useful value for future operations in terminal areas. A rate of once in 4 seconds has been assumed for en route operations (lesser requirements for oceanic service). The surveillance function should have the capability to provide a range of position update rates.

The present FAA policy, which calls for independent surveillance for safety, to provide surveillance services in support of DOD requirements, and to provide service to aircraft with system outages, was recognized. It was agreed that spectrum must be provided to maintain such an independent service. It is believed that in the future, aircraft transponder-based cooperative independent surveillance or automatic dependent surveillance could satisfy the surveillance function, if universal carriage can be assumed. Nonetheless, spectrum should be set aside for independent, non-cooperative, surveillance.

3.3.3 Communication Services

There will be a continuing need for air-ground voice and data communications. It is believed that such services could be provided by commercial services. Guaranteed high-integrity channels will be required for these services, which would also carry the automatic dependent surveillance communications.

If air-ground communication services are most efficiently provided by ground-based systems in high-density terminal areas (to constrain service costs due to high system capacity needs), consideration should be given to satisfying this function at L-band so that most efficient use may be made of the L-band avionics.

A question remained regarding the provision of communication and surveillance services over the polar areas. At a time when it becomes attractive to phase out HF, a means must be found to satisfy this need.

4.0 Radio Frequency Spectrum And Service Sharing Considerations

4.1 Aeronautical Satellite Allocations

The principal portions of the radio frequency spectrum available to the aeronautical community for satellite applications are the 1530-1660.5 MHz and 5000-5250 MHz bands.

In the 1530-1660.5 MHz band, there is 44.5 MHz of exclusive aeronautical spectrum and 51.0 MHz of shared spectrum which is available for space utilization (see Figure 1). The Global Positioning System (GPS), in the SPS portion currently available to the civil community, uses 2 MHz (centered about 1575.42 MHz). The full system, with its dual frequency precision ranging capability, utilizes a total of slightly over 40 MHz (±10.23 MHz each, centered about 1575.42 MHz and 1227.6 MHz).

The 1610-1626.5 MHz segment is a subject of an FCC NPRM addressing future radiodetermination satellite services. The 1545-1559 MHz and 1646.5-1660.5 MHz (satellite-to-aircraft and aircraft-to-satellite respectively) band segments, presently the principal aeronautical mobile-satellite (R) bands exclusively allocated, internationally, to aviation, were systematically planned with suitable diplexer arrangements that were compatible with the adjacent maritime spectrum allocations.

The total 5000-5250 MHz band is available for aeronautical satellite applications with one proviso. Satellite use of this band must not impact operation of the International Standard Microwave Landing System for precision approach and landing operating in the sub-band 5031-5090.7 MHz. The [illegible] MHz band is allocated to the aeronautical mobile-satellite (R) service, the fixed-satellite service, and the inter-satellite service (see Figure [illegible]). Use by the fixed-satellite and inter-satellite services is restricted to use in conjunction with the aeronautical radionavigation and/or aeronautical mobile (R) services. There are no existing U.S. satellite operations in this band.

4.2 Regulated Use of Aeronautical Mobile (R) Bands 1/

International Telecommunication Union (ITU) Radio Regulation 3630 restricts use of frequencies in any band allocated to the aeronautical mobile (R) service to "communications related to safety and regularity of flight between any aircraft and those aeronautical stations primarily concerned with flight along national or international civil air routes." Using the principle imbedded in RR 3630, a strict interpretation would require that frequencies used for aeronautical mobile (R) communications be on an exclusive basis, i.e., not shared with other services. This would rule out any consideration of operating an aeronautical mobile (R) service within a mobile service allocation, for example, even though it would otherwise be appropriate. It would also rule out a band sharing arrangement involving the aeronautical mobile (R) service and another service.

Applying a more liberal interpretation of the international radio regulations, the task group developed conditions for sharing satellites, transponders, frequency bands, and individual channels which would satisfy the intent of ITU Radio Regulation 3630. These conditions are presented in Section 4.4.

4.3 The Service Sharing Issue

One of the principal reasons that aeronautical satellite communications (air-ground) are not currently in use is that satellites dedicated to aeronautical services have not been shown to be cost-beneficial. A form of shared service, whereby several different user groups share the use (and cost) of a satellite transponder or platform, might become cost-beneficial for some aviation services.

1/ Frequencies in any band allocated to the aeronautical mobile (R) service are reserved for communications between any aircraft and those aeronautical stations primarily concerned with the safety and regularity of flight along national or international civil air routes.

There are several ways of sharing—sharing the use of a satellite transponder with a user group which has an adjacent frequency allocation (i.e., the maritime community), or sharing a satellite platform by placing an aeronautical transponder or package onboard (resulting in significant capital [illegible] the aviation community). A third way is sharing of the same frequency spectrum, as would be the case in a sharing arrangement with a regional mobile satellite service. Herein lies the dilemma: on the one hand, space segment resource sharing may well be necessary to provide a cost-beneficial basis for some aeronautical (air-ground) communication services. On the other hand, there are potential problems in this kind of sharing, such as whether such shared service can provide the needed quality of communications to support safety-of-life services, and concern that the band segments could be quickly gobbled up by rapid growth of general mobile service requirements.

Acceptable shared service in these L-band segments would need to satisfy a number of overriding conditions, including:

1. The aviation community would need to be satisfied that their future requirements can be met in these band segments, considering domestic and world-wide aviation needs. This will include the reservation of a portion of the band segments for potential future functions that might not be able to use a shared service (e.g., a high quality/capacity/capability surveillance function for CONUS).

   Adequate capability must be available, at any future time, to meet aeronautical requirements through use of: (a) system capacity from any implemented mobile satellite communication systems utilizing portionsof the presently allocated aeronautical mobile-satellite (R) spectrum, and/or, (b) use of the remainder of the present aeronautical mobile-satellite (R) spectrum (assuming no increase in frequency reuse beyond that utilized in the then existing generation mobile satellite communication systems).

2. Any shared service would need to provide the capability/flexibility for a variety of functions, and be able to operate with user system interface requirements that do not result in an undue cost burden on the user. This aspect is likely to include the consideration of world-wide system compatibility.

3. System integrity and long term reliability--including instant access and priority--aspects are of particular concern in the provision of an aviation safety service, and would need to be carefully addressed.

4. The potential for "uncontrolled" user classes in any shared service needs to be considered.

[illegible] Satellite Service Sharing Conditions

In sharing the same frequency spectrum, satellite transponder, and satellite platform, two arrangements are possible--earmarking (dedicating) specific channels to aeronautical use, and sharing channels.

The shared channel arrangement implies that the channels could be assigned on a shared basis for a number of services (e.g., landmobile and aeronautical), through a slow dynamic demand assignment basis and/or an arrangement in which the number of channels temporarily allocated to aeronautical use could vary over time (e.g., over a daily cycle), depending on aeronautical service needs.

The following conditions are considered essential for the implementation of a shared aeronautical satellite safety service:

1. Aeronautical safety services must be the highest priority services on the satellite (except in the case of a national emergency).

2. National/international agreements will be required to assure the achievements of system standards. These agreements will form the basis for procuring services.

3. The satellite service shall be as transparent as possible regarding the acceptance of various system operational schemes. The aviation community reserves the right to develop and use system designs, including system interface specifications, system accessing techniques, and channel bandwidths, that may optimize service benefits and costs for the aviation community.

A number of system operational conditions/guarantees have been identified as being necessary to make the use of a leased commercial shared satellite communication service for ATC acceptable, considering both dedicated channel and shared channel satellite service sharing arrangements. These conditions/guarantees include:

1. For dedicated channel arrangements, a series of channels (or alternatively, system power/bandwidth capability) must be provided which will contain only the aeronautical safety service. For shared channel arrangements, guarantees must be given to insure that other services potentially sharing the channels do not impact the provision of aeronautical safety services when the channel(s) are assigned to aeronautical use.

2. Shared spacecraft system components, including antennas and transponders, are acceptable as long as they meet necessary reliability/integrity requirements.

3. Loading on nonaeronautical channels/by nonaeronautical services must not reduce the performance of dedicated aeronautical channels or channels assigned to aeronautical use.

4. Dedicated aeronautical channels or channels assigned to aeronautical use must be protected against harmful interference products from any other services utilizing spacecraft.

5. In the case of spacecraft degradation, all other services must be shed before the aeronautical safety services are impacted.

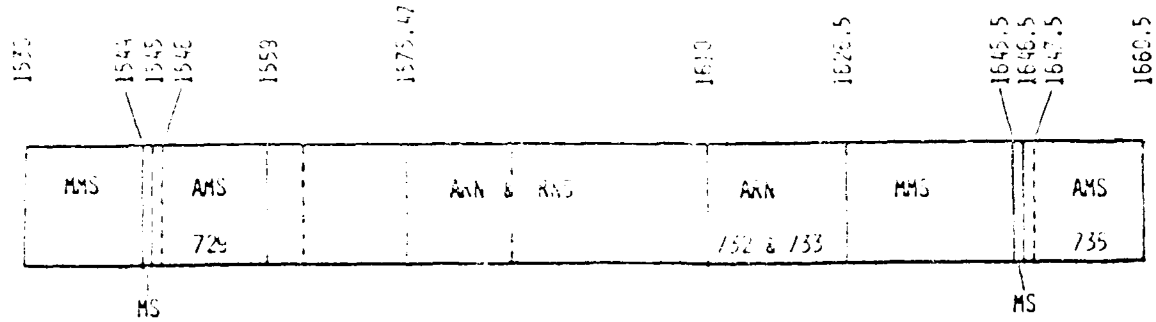
6. Catastrophic failures will be mitigated either by an in-orbit "hot spare satellite," separation of services between two or more satellites, or redundancy of all satellite systems.

7. Operational access to dedicated aeronautical channels must be instantaneous. Operational access to shared channels must also be instantaneous after such channels are assigned to aeronautical use. The time delay between request and assignment of shared channels to aeronautical use must be very short if a dynamic channel sharing arrangement is to be acceptable; acceptable demand access conditions must be guaranteed prior to the use of such an arrangement. For the case of possible time division multiplex channel sharing arrangements, acceptable access and message throughput delay conditions must be met.

8. For shared channel arrangements, the satellite communication system must have the capability, if necessary, to insure that messages provided to the FAA will only be aeronautical safety messages.

Provided that these conditions are resolved satisfactorily and the related system design and operational considerations addressed in the next section are satisfied, the task group believes that satellite service sharing can be an acceptable means of providing a portion of the aeronautical services, including safety services, if sufficient capacity could be made available in the aeronautical bands to also permit their use by other mobile services.

Considering the present mix of FAA owned and operated services, and leased services, the task group saw no reason why a leased satellite service could not support a portion of the aeronautical needs, including safety services, provided that adequate service safeguards were satisfied. Further, the task group did not consider that satellites would have to be dedicated to the FAA, again assuming adequate safeguards.



LEGEND: AMS - AERONAUTICAL MOBILE-SATELLITE (R)

ARN - AERONAUTICAL RADIONAVIGATION

MMS - MARITIME MOBILE-SATELLITE

MS - MOBILE SATELLITE

RNS - RADIONAVIGATION SATELLITE

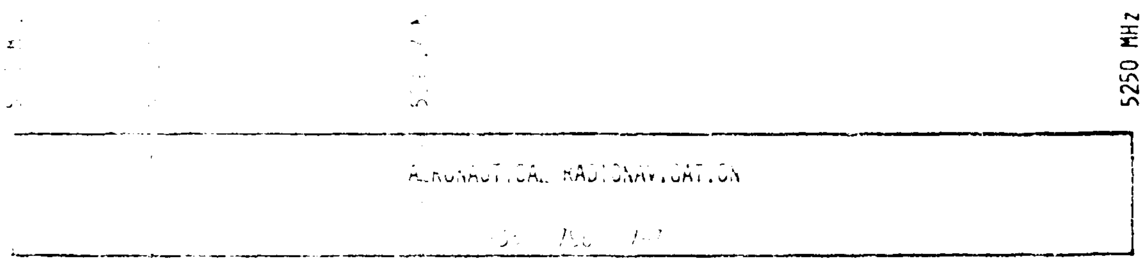
729 TRANSMISSIONS IN THE BAND 1545-1559 MHz FROM TERRESTRIAL AERONAUTICAL STATIONS DIRECTLY TO AIRCRAFT STATIONS, OR BETWEEN AIRCRAFT STATIONS, IN THE AERONAUTICAL MOBILE (R) SERVICE ARE ALSO AUTHORIZED WHEN SUCH TRANSMISSIONS ARE USED TO EXTEND OR SUPPLEMENT THE SATELLITE-TO-AIRCRAFT LINKS.

732 THE BAND 1610-1626.5 MHz IS RESERVED ON A WORLDWIDE BASIS FOR THE USE AND DEVELOPMENT OF AIRBORNE ELECTRONIC AIDS TO AIR NAVIGATION AND ANY DIRECTLY ASSOCIATED GROUND-BASED OR SATELLITE-BORNE FACILITIES. SUCH SATELLITE USE IS SUBJECT TO AGREEMENT OBTAINED UNDER THE PROCEDURE SET FORTH IN ARTICLE 14.

733 THE BANDS 1610-1626.5 MHz, 5000-5250 MHz and 15.4-15.7 GHz ARE ALSO ALLOCATED TO THE AERONAUTICAL MOBILE-SATELLITE (R) SERVICE ON A PRIMARY BASIS. SUCH USE IS SUBJECT TO AGREEMENT OBTAINED UNDER THE PROCEDURE SET FORTH IN ARTICLE 14.

735 TRANSMISSIONS IN THE BAND 1646.5-1660.5 MHz FROM AIRCRAFT STATIONS IN THE AERONAUTICAL MOBILE (R) SERVICE DIRECTLY TO TERRESTRIAL AERONAUTICAL STATIONS, OR BETWEEN AIRCRAFT STATIONS, ARE ALSO AUTHORIZED WHEN SUCH TRANSMISSIONS ARE USED TO EXTEND OR SUPPLEMENT THE AIRCRAFT-TO-SATELLITE LINKS.

US260 AERONAUTICAL MOBILE COMMUNICATIONS WHICH ARE AN INTEGRAL PART OF AERONAUTICAL RADIONAVIGATION SYSTEMS MAY BE SATISFIED IN THE BANDS 1559-1626.5 MHz AND 15.4-15.7 GHz.



[illegible]

733 [illegible] MHz and 15.4-15.7 GHz ARE ALSO ALLOCATED TO THE AERONAUTICAL MOBILE-SATELLITE (R) SERVICE ON A PRIMARY BASIS. SUCH USE IS SUBJECT TO AGREEMENT OBTAINED UNDER THE PROCEDURE SET FORTH IN ARTICLE 14.

796 THE BAND [illegible] MHz IS TO BE USED FOR THE OPERATION OF THE INTERNATIONAL STANDARD SYSTEM (MICROWAVE LANDING SYSTEM) FOR PRECISION APPROACH AND LANDING. THE REQUIREMENTS OF THIS SYSTEM SHALL TAKE PRECEDENCE OVER OTHER USES OF THIS BAND.

797 THE BANDS 5000-5250 MHz AND 15.4-15.7 GHz ARE ALSO ALLOCATED TO THE FIXED-SATELLITE SERVICE AND THE INTER-SATELLITE SERVICE, FOR CONNECTION BETWEEN ONE OR MORE EARTH STATIONS [illegible] ON THE EARTH AND SPACE STATIONS, WHEN THESE SERVICES ARE [illegible] WITH THE AERONAUTICAL RADIONAVIGATION AND/OR AERONAUTICAL MOBILE [illegible] SERVICE [illegible] SHALL BE SUBJECT TO AGREEMENT OBTAINED UNDER THE PROCEDURE SET FORTH IN ARTICLE 14.

FIGURE 2

equip with the necessary satellite transceivers. (Such groups may already exist, i.e., helicopter operators who need ATC services in low-altitude and off-shore airspace where ATC coverage is poor or nonexistent, and oceanic system users who cannot obtain ground-based VHF line-of-sight services except in limited offshore areas.) Finally, proof-of-concept tests would have to be conducted, probably for several years, to gain experience and/or confidence in the system. As such experience/confidence was gained, the service could be introduced into increasingly complex or dense airspace on an orderly basis. Such an approach requires no dramatic switch in ATC systems or procedures; allows a gradual, cost-effective means for transition; and permits the concept to evolve to whatever level of implementation is deemed appropriate.

[illegible] System Content Functions

[illegible] Navigation

The aircraft horizontal position information used for navigation and as [illegible] source for automatic dependent surveillance could be obtained from [illegible] RNAV systems still in service by 2010; the performance of such [illegible] separation minima of the airspace in which [illegible]

[illegible] Section [illegible] satellite navigation is likely to be the [illegible] horizontal navigation service for the 2010 time frame, with [illegible] system as the likely system candidate for this service. [illegible] to provide the vertical [illegible] information is [illegible] operations [illegible] check, [illegible] CAT III [illegible] needed in [illegible] to a suitable level. Future analysis [illegible] reliability of the [illegible] GPS will need to determine whether

encoder in the aircraft to determine altitude. It is interesting to note that in no airspace do we truly have an independent surveillance system, since we are always relying on the aircraft (pilot) to provide at least one piece of essential information to the ATC system.

Thus, the concept of operationally using dependent surveillance is well established in the ATC system. The question is, to what degree can this function be extended to achieve an ATC system totally based on dependent surveillance. The answer lies with the accuracy of the navigation systems being utilized, the reliability and integrity of the navigation system(s) and the communications system elements used to transmit and receive the information, the system redundancy to assure that a single failure does not cause the loss of both navigation and surveillance, and the confidence of all parties concerned in using such a system.

Technology is moving rapidly to solve the accuracy, reliability, and integrity issues raised above. It is possible today to buy RNAV receivers based on VOR/DME, LORAN-C, DME/DME, OMEGA/VLF, and, in the not-too-distant future, GPS. For the purpose of this discussion, the source is not important (although the accuracy clearly depends on the source), but rather the fact that it is becoming increasingly more common (and cost-effective) for a large class of aircraft to have onboard position determination systems. Thus, the nucleus for an automatic dependent surveillance system is being created at the present time. What is needed is a system to transfer this onboard information to the ATC system at a sufficient update rate to be used for ATC purposes. One way to do this would be to use a satellite link as the transmission medium.

How could such a system be introduced into the ATC system in an orderly, systematic way? First and foremost, there would have to be a commitment on the part of the FAA and users to move toward such a system. Second, a satellite link would have to be provided. Such a link could be a subsystem on a variety of commercial or government-owned geosynchronous satellite systems. Third, a certain set of users would have to be willing to

is discussed. It allows the ATC system to be extended to areas where, today, few or no services are available, and to evolve to other areas as onboard position determination accuracy, reliability, and integrity improve to a level consistent with the separation standards needed. It also establishes the potential bandwidth requirements which would be necessary for the satellite system which would be used to support the system.

Accurate and timely position determination of aircraft is essential to the proper functioning of any air traffic control system. The more accurate the determination is, the smaller separation standards can be in any particular airspace. Today, separation standards are based on the capability of the navigation system to achieve an acceptable level of performance and the capability of the surveillance function to monitor aircraft separation and navigation performance on a real-time (or near real-time) basis. Surveillance for such high-traffic density areas as CONUS are based principally on some form of radar (primary or secondary). However, if one could be assured that regardless of the source of the position determination, it would be accurate, timely, and reliable. There is no reason why it must be independent from the aircraft's onboard navigation systems. If one can accept the principle that [illegible] should be [illegible] the reliability and integrity of onboard [illegible] the concept of air traffic control based on dependent surveillance deserves consideration.

In today's airspace, there are three principal methods used to locate aircraft and provide separation services. First, in low-density airspace where no radar coverage exists, we rely on pilot position reports based on [illegible] specific navigation fixes. This is dependent surveillance, i.e., the surveillance is dependent on the navigation system position data. In certain other airspace, we have elected to use Beacon-only radars with automatic altitude reporting, thus providing a form of independent surveillance so long as the airborne equipment (transponder and encoding altimeter) are working. Finally, in high-density terminal airspace and most, if not all, of the high-altitude en route airspace, we provide both primary and Beacon radar coverage. But, even here we must rely on either a pilot report or an altitude

7. Future System Concepts

The task group considered the nature of future air traffic system management, the mid-1990's baseline ATC system following implementation of the National Airspace System Plan, and new ATC concepts for the 2010 time period. A discussion of these subjects, including overviews of the system concepts for 2010 which are considered in more detail below, is presented in Section 2.

The concepts considered below focus on providing services for anticipated continental U.S. traffic (see Section 5). Consideration for global service has been given, resulting in the following design philosophy assumptions: There will be several areas of the world, which would have a sufficiently large user base (possibly not limited to aviation) to justify the cost of a satellite system employing multiple beams and a fair degree of frequency reuse. Other areas of the world would have service from satellite systems employing larger beams giving little opportunity for frequency reuse. All the services would have overlapping coverage to provide continuity of service on a global basis. It is assumed that when the user base of an area and service demands grow to a substantial level, that area would also justify the use of a multiple beam satellite system employing frequency reuse. It is assumed that the basic functions considered below, including voice and data communications, automatic dependent surveillance, and global satellite navigation services, are adaptable throughout the world.

7.1 Automatic Dependent Surveillance Based Concept--Concept 1

7.1.1 Introduction

It is the intent of this section to develop an ATC system operational concept based on automatic dependent surveillance as the primary means for insuring separation, and to illustrate how it could be introduced in a systematic way, based on the accuracy of the navigation systems being used and the airspace involved. A viable concept for introducing automatic dependent surveillance, using a satellite link as the transmission medium for the surveillance data,

TABLE 6-2
TERMINAL COMMUNICATIONS (DIGITAL)

SATELLITE LINK PART	FUNCTION	PER AIRCRAFT AVE BPS		PER AIRCRAFT PK BPS
o Aircraft to Ground	o ATC - Tactical (ack.) - Automated clearance (req.)	8.4	x10	84
	o Flight Services (req.) - Urgent ETIS - Routine ETIS - Digitized Wx	0.3	x10	3
	o Automated Dependent Surv. - Position - Extended Position	500		500
	o Wind Report	7.5		7.5
	o Total per aircraft			594.5
	o Total for 7.5K aircraft			4.5 MBPS
o Ground to Aircraft	o ATC - Tactical - Automated Clearances	40	x5	200
	o Flight Services	4.6	x5	23
	o Traffic Advisory (assumes 10% A/C)	50		50
	o Total per aircraft			273
	o Subtotal per 7.5K aircraft			2 MBPS
	o Broadcast - All Call - Nav. System Integrity - Nav. System Differential	100 20 90 210		100 20 90 210
	o Total for 7.5K aircraft			2 MBPS

TABLE 6-1

EN ROUTE COMMUNICATIONS (DIGITAL)

SATELLITE LINK PART	FUNCTION	PER AIRCRAFT AVE BPS		PER AIRCRAFT PK BPS
o Aircraft to Ground	o ATC - Tactical (ack.) - Automated clearance (req.)	8.4	x10	84
	o Flight Services (req.)	0.03	x10	0.3
	o Automated Dependent Surv. - Position - Extended Position	125		125
	o Wind Report	2		2
	o Total per aircraft			211.3
	o Total for 42.5K aircraft			8.97 MBPS
o Ground to Aircraft	o ATC - Tactical - Automated Clearances	8.4	x10	84
	o Flight Services	2.3	x10	23
	o Traffic Advisory (assumes 5% A/C)	6.5	x10	65
	o Total per aircraft			172
	o Subtotal per 42.5K Aircraft			7.3 MBPS
	o Broadcast - All Call - Nav. System Integrity - Nav. System Differential	100 20 90		100 20 90
		210		210
	o Total for 42.5K aircraft			7.3 MBPS

The digital data to support automatic dependent surveillance (item d) includes the aircraft ident, state vector (or pseudo ranges from GPS), barometric altitude, and altitude rate. This data is transmitted at a 1 Hz rate for terminal area applications and at a 0.25 Hz rate for en route operations. An extended position report is also provided to permit ground control to detect flight paths that appear to be inconsistent with the flight plan. As noted from Tables 6-1 and 6-2, the data requirements to support automatic dependent surveillance dominate the other service because of the relatively high update rate per aircraft.

The aircraft counts used in Tables 6-1 and 6-2 were obtained from Section 5. By using the peak counts in CONUS, an upper bound on the communication requirements can be obtained.

The emergency traffic advisory is provided to aircraft that are in the vicinity of another aircraft whose navigation or communication equipment failed. It is assumed that 10 percent of the aircraft in terminal areas and 5 percent of the aircraft en route would be affected at any one time.

The broadcast data is used to provide all aircraft in a particular geographic area with time synchronization and acquisition of the common channel, navigation system integrity, and navigation system differential corrections. The time synchronization* and acquisition allows an aircraft to obtain appropriate time slots in which to transmit.

The Per Aircraft BPS estimates presented in Tables 6-1 and 6-2 include allowances for protocols and Rate 1/2 error correcting coding.

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*The time synchronization also allows the ground terminal to obtain an independent measurement of range to the aircraft for use as an independent monitor of the position report.

6. Estimates of Required Information Flow

This section presents estimates of information flow for air-to-ground and ground-to-air digital data communications for a high density area (in this case using the continental U.S.), which were based upon the traffic forecasts developed in Section 5 and on previous studies of ATC data link communication functions. Information flow estimates for voice communications were not developed; instead, estimates for frequency spectrum needs for voice services were based on consideration of present voice services as presented in Section 8.

6.1 Digital Data Communication Flow Estimates

The digital data communication flow estimates are presented in Tables 6-1 and 6-2 for en route and terminal area communications, respectively.

The data message types include the following:

a. ATC tactical messages
b. Flight service
c. Aircraft-derived wind reports
d. Automatic dependent surveillance
e. Emergency traffic advisories
f. Broadcast data
g. Operational and administrative communications

The data content to provide items a through c were derived from Reference 1 (FAA-RD-81-14). Other data were added to permit future ATC services such as time navigation and definition of fixed paths in terminal areas. For ATC and Flight Services communications, the average number of messages from Reference 1 was converted to bits per second (BPS) per aircraft using the Mode S data format. The average BPS was converted to peak BPS assuming a factor of ten. The Mode S data format was also used to estimate the peak BPS for all digital data functions.

Section 5 - References

1. National Airspace System Plan, by FAA, April 1984, Chapter II.

2. Aviation Week and Space Technology, December 3, 1984 Issue, Page 53.

3. Advanced Air Traffic Management System Study, Technical Summary by the Transportation Systems Center, Report #DOT-TSC-OST-75-6, March 1975, Chapter 2.

4. Regression Model for Forecasting Instrument Flight Rule Aircraft Activity at Twenty-five Air Route Traffic Control Centers, and related study efforts carried out by Applied Systems Institute, Inc., Under Contract DOT-FA79WAI-071, February 1980.

5. Report on Terminal Air Traffic Density Measurements, by M. Gonzalez, FAA, OSEM Technical Letter Report #EM-82-1-LR, July 1982.

6. A Study of the Communications Requirements for a 1985 to 2000 Operational Aeronautical Satellite System, by Danny E. Cornett, et al., ARINC Research Corporation, Report #FAA-RD-75-80, 3 Volumes, May 1975 and March 1976.

7. Oceanic Area System Improvement Study (OASIS), by G. J. Couluris, et al., SRI International, Report #FAA-EM-81-17, 10 Volumes, September 1981.

8. Forecasts of Transpacific Air Travel 1975, 1980, and 1985, by Michael Jay Roberts, Booz-Allen Applied Research, Report #FAA-RD-73-58, October 1973.

9. Forecasts and Analysis of International Air Traffic In Relation to Transoceanic Communications Requirements, James Gorham, et al., SRI International, Report #FAA-RD-77-131, December 1977.

10. Helicopter Forecasting Study, Regional Helicopter Forecasts, by Applied Systems Institute, Inc., under Contract DTFA-01-83-Y-30553, December 1984.

This data seems reasonable from the standpoint of considering realistic and meaningful estimates of future traffic-related statistics which could be used as an input for projecting a bound on foreseen future ATC services. This data was developed assuming the projected continuing growth trend of the present air transport system. It will be seem from the computations in Section 6 that within the information flow categories, there is an essentially linear relationship between aircraft served and spectrum required. The table clearly indicates that the service demands will be dominated by a high traffic density area such as the continental U.S.

SRI International Study (Ref. 9)

Including All Scheduled Traffic		1980	1985	1995
Total Atlantic Basin, Including Most of Africa and South America, PIAC	:	594	705	1038
North Atlantic, PIAC	:	355	422	620
Caribbean, PIAC	:	162	---	282
South Atlantic, PIAC	:	43	---	82
Pacific Basin, PIAC	:	---	713	1572

Consideration has also been given to including Gulf of Mexico traffic, including helicopter traffic, into the overall Caribbean PIAC. A total of 75 and 100 helicopters estimated for the year 1995 and 2010 respectively, are included in the Gulf of Mexico traffic (Ref. 10). Based upon this information, the estimates of PIAC's presented in Section 5.7 for these regions have been selected for consideration in the study.

5.6 Canadian, Mexican/Central American, and South American Traffic

The SRI International study (Ref. 9) includes estimates for PIAC's for South America (153 and 315 for 1980 and 1995 respectively). Estimates have been made for the other areas which are considered reasonable. The estimates considered in the study for these areas are presented in Section 5.7.

5.7 Summary of PIAC Traffic Estimates

The following table presents a summary of the estimates of PIAC's considered in the study for the various geographic areas and cases.

	PIAC's	
Area/Case	1995	2010
Continental U.S.	--	50,000
Busy Center (Enroute Traffic)	--	5,000
Busy Terminal Area	--	1,500
Continental U.S. Traffic in Terminal Areas	--	7,500
Canada	2,500	4,000
Mexico/Central America	300	600
South America	300	600
North Atlantic	500	800
Caribbean/Gulf of Mexico	275	400
South Atlantic	80	150
Pacific Basin	600	1200
Central East Pacific	110	200

by FAA and completed in 1981, only considered aircraft in oceanic flight information regions and those flying above 24,000 feet in altitude (Ref. 7).

Several other traffic forecast studies not explicitly including ATC system improvement aspects have been considered. These included a 1973 study by Booz-Allen Applied Research (Ref. 8) and a 1977 study by SRI International (Ref. 9). The Pacific traffic forecast developed in the SRI International study (Ref. 9) might be considered somewhat high for the purposes of this analysis, since the geographic areas include some overland regions that might otherwise be considered as domestic system areas.

The following data summarizes the findings of the 4 studies considered (Refs. 6-9).

ARINC Study (Ref. 6)

	1975	1980	2000
Atlantic Basin, PIAG :	150	170	370
Pacific Basin, PIAG :	120	140	380

SRI International OASIS (Ref. 7)

	1979	2005
North Atlantic, IAC :	170	230
Central East Pacific*, IAC :	46	109

Booz-Allen Study (Ref. 8)

	1980	1985
Pacific Basin, PIAC :	323	431
Honolulu-CONUS, PIAC :	87	92

* The Central East Pacific Traffic is predominantly the traffic between the North American West Coast and Hawaii.

5.3 Busy Center PIAC

Considering the enroute traffic PIAC's that may be needed to be serviced by each of the 20 U.S. Air Route Traffic Control Centers, the highest PIAC for the year 2000 is projected for Chicago, about 3,600 aircraft (Ref. 4). Therefore, it does not seem unreasonable to estimate that a U.S. Center may need to service an enroute traffic PIAC of up to 5,000 aircraft by the year 2010.

5.4 Busy Terminal Area PIAC

The PIAC for a busy terminal area, i.e., a high traffic density area possibly involving a number of airports, is also an important parameter for analysis, since terminal area traffic may require additional services, such as surveillance position reports at a higher rate and additional communications. A busy hour demand of 500 operations per hour has been projected for the year 1995 for the New York City area, considering the three large city airports (Ref. 3). An IAC of over 1,000 aircraft has been projected for the Los Angeles area (within a 50 mile radius) for the year 1995 (Ref. 5). Therefore, a PIAC for such a busy terminal area for the year 2010 of 1500 aircraft has been selected as a bounding value. A total of 15 percent of the U.S. PIAC, or 7,500 aircraft is assumed to be in terminal areas.

5.5 Atlantic, Pacific, and Caribbean Traffic

Many studies investigating improvements for these areas have been carried out over the past 20 years. However, since a number of good studies concentrated upon "filling gaps" in the present ATC systems, the related traffic forecasts projected by these studies distort the actual levels of traffic for these areas. The ARINC Research Corporation Communications study carried out for the FAA in the mid-1970's projected PIAC's (i.e., the peak instantaneous aircraft in the communications gap, or outside of line-of-sight communications coverage) instead of PIAC's for the entire areas (Ref. 6). The SRI International Oceanic Area System Improvement Study (OASIS), also sponsored

5. Traffic Forecasts and Traffic Loading/Distribution

5.1 Introduction

Traffic forecasts, by definition, are always wrong, especially when looking ahead for a period of 25 years to the year 2010. At the present time economic conditions seem to be projecting an optimistic future of growth for traffic. The NAS Plan projects aviation activity to nearly double in the next 20 years (Ref. 1). Recent projections from a consensus of 11 aircraft and engine manufacturers and suppliers indicate a more than 5 percent annual growth in worldwide airline traffic through the mid-1990's, with non-U.S. traffic gains outstripping U.S. gains (Ref. 2).

Considering these optimistic views of the future, but realizing that there will probably be ups and downs as well as diverse opinions, the objective of presenting the projections in this section is to attempt to bound the need for future services. Therefore, only one set of estimated future traffic is provided; the future traffic levels are not considered to be unreasonably high considering the range of possibilities. The traffic data is provided in terms of Peak Instantaneous Aircraft Count (PIAC); that is, the largest number of aircraft actively flying in the ATC system being considered and requiring services.

5.2 U.S. Domestic PIAC

Over the last decade a number of estimates have been made of the PIAC for the continental U.S. A study performed as part of the Advanced Air Traffic Management System Study in 1975 estimated the PIAC to be 37,000 by the year 1995 (Ref. 3). More recent projections prepared as part of a forecast study carried out for the FAA Office of Aviation Policy in 1980 estimated the PIAC to be as high as 45,000 by the year 2000 (Ref. 4). For a number of years a PIAC of 50,000 aircraft for the U.S. has been projected for the first decades of the next century. Therefore, based upon presently available data, a value of 50,000 PIAC has been selected as a reasonable value for the year 2010 to be used in the analysis.

and to what extent back-up or fail-soft modes are required (e.g., the need to carry another navigation sensor besides GPS or to have a means to coast through satellite or other system failures).

7.1.2.2 Communications

Mobile satellite systems are being proposed by private industry to provide voice and data communications to mobile users. Since the intention is to attract large classes of users (besides aviation), and low-cost technology exists to provide similar services, the satellite service to succeed will have to be low cost. The technology being developed by industry to provide cost-effective service includes the use of spot beam antennas to provide less expensive EIRP through higher spacecraft antenna gains and spectrum use efficiency through frequency reuse.

A large amount of the ATC-related communications in the 2010 time frame will be via data link services. In the terminal area, however, some level of voice communication may be retained to permit the pilots to retain a mental picture of the traffic environment via the "party line." A multiplexed digital communications link could permit the transmission of voice and data in the same channel.

The communication services are assumed to be provided via commercial satellites. FAA would negotiate dedicated channels over most of CONUS with an option to expand the number of channels as the demand requires. For example, the demand for channels from midnight to 6 a.m. is not as great as the demand during peak traffic hours. In low-traffic areas (e.g., in remote areas, over the oceans, etc.), the channels can be shared with other users as long as the aeronautical safety service has preference to the channel. Each channel is designed to accommodate digital data.

In terminal areas, compatible terrestrial-based L-band voice and data communication services are assumed to be provided to effect a more economical service, to provide increased performance (e.g., to provide continuous

coverage during aircraft maneuvers), and/or to provide a back-up system to the satellite service. The L-band terrestrial system would make it possible to use the same avionics for all communication services, and therefore could effect user equipment economies. Frequency spectrum needs for these services are presented in Section 8.

The data link communication flow for the continental U.S. for the 2010 time frame has been estimated in Section 6 based on forecasts of traffic developed in Section 5. A significant amount of the data link communications in the aircraft-to-ground direction is from automatic dependent surveillance position reports. The communications also include system integrity messages related to the evolved GPS, as indicated in Section 6. Information flow estimates for voice communications were not developed; instead, estimates for frequency spectrum needs for voice services were based on consideration of present voice services as presented in Section 8.

The capability, accessibility, reliability, and integrity of a satellite communication system shared service are issues of prime importance for the aeronautical safety services, and are discussed in detail in Sections 4.3 and 4.4.

7.1.2.3 Surveillance

Automatic dependent surveillance, using satellite communications to relay the position reports, is assumed to be the primary surveillance service for all areas.+ Primary radar is assumed to be available in terminal areas and would be used to detect unequipped aircraft or aircraft whose automatic dependent surveillance related equipment had malfunctioned.*

+Provision may be made to enable ATC to obtain an independent line-of-position using a range measurement with the communications channel (in conjunction with time synchronization) and altitude from the altimeter.

* The primary radar is also used to detect bird formations and local weather in terminal areas.

The position report data that would be automatically transmitted to the ground system would be taken directly from the navigation equipment without change by the pilot, and therefore would indicate the position of the aircraft (to the equipment accuracy limits). Pilot blunders can be detected at any time if the waypoint data being used for navigation is compared against the cleared flight plan. Because of the improvements in the GPS accuracy, avionics reliability, and the use of redundant altitude information, the proposed automatic dependent surveillance-based system is assumed to be at least as safe as the current system. In addition, automatic transmission of position in lat/long coordinates makes it easier for a particular controller "radar" position to accurately display the position of all aircraft.

The transmitted information would include such information as aircraft ID; navigation sensor(s), latitude, longitude, and barometric altitude, GPS altitude (if available); and GPS psuedo ranges. An extended position report is provided by suitably equipped aircraft and includes the above plus heading, ground speed, airspeed, and altitude rate. This position report provides the primary surveillance information used by the ATC system. This information is transmitted at a rate commensurate with the airspace:

The rate over oceanic could be once every 10 seconds, the rate for U.S. en route airspace is assumed to be once every 4 seconds, and the rate in terminal areas is assumed to be once per second. The extended position report is transmitted upon request by ATC and whenever one of the parameters exceeds some specified amount. The extended position report may be used by ATC to reduce the size of the airspace buffer being protected due to the uncertainties and delays in the system.

7.1.2.4 Collision Avoidance

The TCAS may still be in use as an independent airborne collision avoidance function in the 2010 time period. Alternatively, a collision avoidance function may be implemented in conjunction with the availability of GPS derived automatic dependent surveillance position reports.

7.1.3 Summary of User Equipment Requirements

A minimum airborne avionics complement is two suitable navigation receiver/processors and one communications transceiver/processor to satisfy the ground rule that no single system element failure may simultaneously eliminate the capability for cockpit navigation and ATC surveillance.

MLS would be required if CAT II and III precision landing operations are needed. Independent airborne collision avoidance equipment is optional.

It should be recognized that the above avionics complements do not cover avionics capability that might be desired in large transport aircraft such as inertial reference systems.

7.1.4 Summary of Service Provider System Requirements

Providing that the satellite air-ground communication services could be a leased satellite service (including the ground station capability) the FAA's system elements would be limited to the terminal primary radars, the terrestrial-based L-band air-ground communications sytem, MLS and the ATC data processing and automation systems at ATC facilities.

7.1.5 System Fail Operational Capability

The following back-up modes are inherent in the system concept assuming the minimum avionics complement of two GPS receiver/processors and one communications transceiver/processor:

(1) An aircraft that fails to transmit its position either because of a failure in the navigation or communication equipment is expected to revert to a procedural plan (e.g., continue at VFR altitudes to the nearest airfield or to the destination along the route filed in the flight plan). When ATC detects the failure it automatically increases the size of the airspace buffer around the projected position of the aircraft and advises other aircraft in the vicinity of the cleared flight path of the failed aircraft.

(2) In order to enter controlled airspace an aircraft will require operating navigation and communication equipment. In the event of a navigation failure after entering the airspace, surveillance and dependent navigation will be provided using primary radar with either the digital data link via satellite or terrestial voice communications.

(3) A collision avoidance system (CAS) is used by equipped aircraft to provide additional protection in a system failure mode, and to protect against undetected system errors.

(4) In terminal areas where terrestial L-band voice and data communication services are implemented, both the satellite and terrestial communication services will be available and will provide protection against communications system outages.

7.1.6 Summary of Satellite-Related Spectrum Requirements

The following table summarizes the L-band spectrum requirements estimated to be needed to support this concept in the 2010 time frame. This data was obtained from Section 8 considering the functions included in this concept. All the L-band spectrum/service capability could be provided by a shared service except for the terrestial voice and data service.

Table 7.1: L-Band Spectrum Requirement for Concept 1[1]

Function	Downlink 1545-1559 MHz	Uplink 1646.5-1660.5 MHz
Space Digital Comm	3.3	4.8
Space Voice Comm.	1.2	1.2
Terrestial Voice & Data (including a 1 MHz buffer in the downlink)	2.4	1.65
Adjacent Geographic Areas	1.0	1.0
	7.9 MHz[2]	8.65 MHz[2]

Notes:
1. The L-band spectrum for GPS is not included in this table (see Section 8).
2. 5.5 MHz of the 7.9 total and 7 MHz of the 8.65 MHz total could be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 were fully satisfied.

The earth station-satellite link spectrum to satisfy this concept has not been identified.

7.2 Cooperative Independent Surveillance-Based Concept - Concept 2

7.2.1 Introduction

The concept developed in this section is based on the premise that the aviation community will not support the use of automatic dependent surveillance as a primary surveillance system in the continental United States (CONUS), even though it is anticipated that after several years of experience with GPS as a new navigation system, the level of reliability of GPS satellite service will support its use of a primary navigation source. As a result, some form of cooperative independent surveillance system will be required.

This concept assumes that space technology will progress to the point where reliable satellites can be developed, fabricated, launched, and operated at a cost level that will enable FAA to deploy a CONUS-wide satellite surveillance system. This will enable an eventual phase-out of all of the en route Mode S ground-based sensors. During a transition period, both satellite and ground-based Mode S surveillance will be operating concurrently.

The satellite surveillance system concept used here is based on studies currently being performed for FAA. The concept calls for 5-7 geosynchronous satellites plus 3 in-orbit spares. The frequency of operation is nominally 1550, rather than 1030 and 1090 MHz. A 4 MHz bandwidth is employed, plus satellite-to-ground links at K-band.

Satellite service is expected to be provided to the earth's surface throughout the CONUS and in immediate off-shore waters. As a result, surveillance service will be provided for helicopters operating in the Gulf of Mexico, in urban areas, and remote areas not previously covered by the ground-based Mode S system. Coverage is limited to the CONUS because of the high cost of extending the service to oceanic areas---separate satellites would be required.

Traffic management service coverage could be maintained to the earth's surface everywhere in the CONUS, if desired. Altitude will be measured by the system and checked against the reported altitude. In this manner, aircraft in the system with inoperative or malfunctioning altimeters or encoders can be accommodated.

In the current Mode S concept, aircraft send their identification codes and altitude reports to ATC upon receipt of interrogation. Mode S also provides a data link which enables ATC clearances and weather information to be sent from ATC to the aircraft. In turn, aircraft can also send other information through this link. However, it is anticipated that the data link functions will be discontinued in favor of an integrated L-band communications system, as with Concept 1. Consequently, the satellite surveillance system concept described here does not include a data link, but assumes only aircraft identification and altitude will be transmitted.

The L-band satellite data/voice link is expected to carry all other data, and will additionally support voice communications. While most ground-air communications will be conducted without voice contact between controllers and pilots, voice channels will be maintained for nonroutine and emergency communications and possibly some party-line communications.

As with Concept 1, the primary navigation system is assumed to be GPS or its evolutionary descendent. Integrity messages and differential corrections (if used) will be transmitted over the L-band satellite communications link. GPS may be able to provide CAT I service, including horizontal and vertical guidance. MLS transmitters will be used for locations requiring CAT II and CAT III service.

Since independent satellite surveillance service is anticipated to be available only in the CONUS and adjacent areas, automatic dependent surveillance will be used in oceanic areas. GPS, which is available worldwide, is expected to be the primary source of navigation information.

During the period when Mode S transponders are required equipment, collision avoidance will utilize TCAS. Once the transition to the satellite surveillance system has been completed, collision avoidance protection can be obtained by processing the surveillance unit squitters of other aircraft, or by reading their L-band position reports.

7.2.2 System Concept Functions

With satellite-based surveillance, navigation, and communication traffic management service coverage can be extended down to a height dictated by traffic density, terrain, and other operational considerations, rather than by the limitations of ground-based sensors. Surveillance service is expected to be provided throughout the CONUS down to the earth's surface for those aircraft requiring or desiring it. Helicopter operations will be fully supported with navigation, communication, and surveillance services over the CONUS and offshore. VFR flights will require voice or data communications to fly into or out of airports with control towers. To operate in a terminal area, a minimum surveillance transmitter will also be required on-board. An aircraft conducting an IFR flight will additionally require navigation equipment. It will be possible for non-precision approaches to be conducted to airports within an en route sector using GPS.

7.2.2.1 Navigation

Navigation service is expected to be provided by GPS, which will support all en route, oceanic, and terminal requirements, as well as non-precision and CAT I precision approaches. MLS will provide CAT II and CAT III service.

7.2.2.1 Communications

Communication of data will be accomplished by using the L-band data link. It is anticipated that much of the ATC routing, instructional, and clearance communications will be sent on the data link. Voice communication will be available for nonroutine, emergency, and possibly other special services.

Unlike Concept 1, aircraft position reports to ATC will be issued much less often, i.e., about once every 10 seconds. As a consequence, the loading on the L-band uplink (aircraft to satellite to ground) communications links will be much smaller, about 50 percent of the loading of Concept 1.

7.2.2.3 Surveillance

Throughout the CONUS and adjacent areas, surveillance will be obtained via the satellite cooperative independent surveillance system. It is anticipated that in high-density areas, aircraft units will squitter at about once per second, elsewhere at about once every four seconds. Current studies indicate that the squitter mode of operation can support an instantaneous airborne count of 30,000.

Two concurrent squitter modes are possible: the GPS-synchronized mode and the unsynchronized mode. In the GPS-synchronized mode, the aircraft surveillance unit transmissions are timed to epochs derived from the GPS navigation system. In the unsynchronized mode, the aircraft unit transmits periodically without reference to any satellite-to-aircraft signals. Synchronization makes possible one-way ranging, which increases the accuracy and reliability of the surveillance measurement. It also enables a collision avoidance capability.

Over-ocean flights will operate outside the coverage area of this satellite surveillance system. Since the density of oceanic traffic is assummed to remain low and separation minima are assumed to be greater than high traffic density areas, there will be no need for a cooperative independent surveillance system. As in Concept 1, the primary surveillance function will be automatic dependence surveillance.

7.2.2.4 Collision Avoidance

TCAS may still be in use as an independent airborne collision avoidance function in the 2010 time period. The Mode S-based airborne collision avoidance equipment may eventually evolve to utilize the satellite

surveillance system aircraft squitters in the CONUS and adjacent areas. Aircraft can obtain protection against other aircraft whose squitters are synchronized with GPS time by purchasing a passive CAS receiver/processor. In oceanic areas, collision avoidance protection can be obtained by a receiver/processor which detects the L-band data transmissions (required for automation dependent surveillance) of other aircraft and reads their position reports. The reports are anticipated to transmit about every 4 seconds.

7.2.3 Summary of User Equipment Requirements

A minimum airborne complement of avionics is one GPS navigation unit (two suitable navigation units for oceanic airspace where cooperative independent surveillance is not available); one surveillance unit, which transmits at least in the unsynchronized squitter mode (altitude reports must be included in the squitters) and an L-band communications transceiver/processor for voice and data communication.

MLS would be required if CAT II and III precision landing operations are needed.

It should be recognized the above avionics complement does not cover avionics capability that might be desired in large transport aircraft such as inertial reference systems.

Collision Avoidance equipment is optional.

7.2.4 Summary of Service Provider System Requirements

The navigation and communications system requirements are the same as [illegible] Concept 1.

In addition to the 5-7 geosynchronous satellites, the surveillance system consists of a ground station and a network of calibration and [illegible] equipments.

Each satellite will employ a number of beams to cover the CONUS and adjacent areas. The concept currently being studied calls for 45 beams, each covering an area about 300 miles across. Several satellites will be capable of transmitting the synchronizing signal. The squitter transmissions of the aircraft will be received by all the satellites in view (typically 4 or 5). Each satellite will act as a repeater, with a channel assigned to each beam. High-gain antennas at the ground control station enable each satellite to use the same frequencies.

The signals from the satellites will be received at two control centers, one to back up the other. The aircraft position reports will then be distributed to the ACF's. En route traffic management can be performed either at a single center, or at the ACF's.

Several stationary ground transmitters will be located within each beam spot at known locations. They will be used to monitor the signal quality and timing. Their transmissions will also provide a means for compensating for satellite drift and ionospheric delays. They will also provide local barometric pressures via the altitude report on the transmissions.

7.2.5 System Fail Operational Capability

In concept 2 the fail operational capability is similar to that of today's system. A loss of navigation capability on one aircraft will be handled by a combination of surveillance and communications, whereby a controller provides approach and landing instructions or reroutes the aircraft. A loss of surveillance will be handled by a combination of navigation and communications; the L-band data link will provide postion reports of the incapacitated aircraft. A loss of communications will be handled by ATC providing additional separation around the incapacitated aircraft. The pilot can use the surveillance system to inform ATC of his plight, because a few data bits will be available in the aircraft message for this purpose.

Within each function there is considerable system redundancy that mitigates against a loss of function what would affect a large number of aircraft.

For over-ocean flights, aircraft will be required to carry two GPS sets, or one GPS set plus another navigation unit. This is to meet the ground rule that no single system element failure should simultaneously deprive the aircraft of both navigation and surveillance.

As with Concept 1, the navigation system involves extra satellites and ground monitors which enable full coverage with several satellite failures. Similarly, the L-band communications system has multiple satellite transponders and channels which can accommodate satellite component failures.

In the satellite surveillance system there are spares which can be activated in case of a satellite failure. The loss of a satellite would reduce the accuracy of the surveillance measurements, but would not cause a loss of the surveillance function. Several aspects of the system concept provide this robustness. If the squitter transmissions of the airborne [illegible], an additional level of reliability is [illegible] made possible by the [illegible] required to establish the aircraft's position. Also, since the altitude report in each squitter can be read by any satellite in view, this information, along with the range measurements from [illegible] satellites, would give degraded, but adequate, position accuracy.

The automatic dependent surveillance mode of Concept 1 could be used as [illegible] of a widespread loss of satellite services, for example, a [illegible] in one or more satellites. Aircraft in the affected area [illegible] message from the central control center via the L-band data [illegible], upon which each aircraft would begin reporting navigation-derived position [illegible] once per second. This would cause a sudden surge in communi[illegible]. As a result, some extra capacity should be available to [illegible] such an eventuality.

If "primary" radars are retained in the terminal areas, they could serve as a backup for the satellite surveillance system.

7.2.6 Summary of Satellite-Related Spectrum Requirements

The Standard Positioning Service of the GPS occupies 2 MHz at 1575 MHz. It may prove adequate, if differential GPS is used, to provide CAT I precision landing service. Alternatively, the additional spectrum now used for high-precision applications may become available. If so, the full 1565-1585 MHz bandwidth of the GPS may be used, as well as the second GPS band at 1217-1237 MHz. The uplink controlling the satellites from the ground stations employs 2 MHz at S-band (1784 MHz). The downlink uses a similar 2 MHz assignment at 2228 MHz.

The use of the 1030/1090 MHz frequencies will eventually be phased out as the ground Mode S sensors are removed. It is estimated that the satellite surveillance system would require about 4 MHz for the aircraft-to-satellite link and about 1 MHz for the satellite-to-aircraft link, assumed to be in the 1646.5-1660.5 MHz and 1545-1559 MHz L-band segment respectively. The satellite/ground (space-to-earth backhaul link) requires a total of 200 MHz in a Fixed-Satellite band, assumed here to be at 20.2-21.2 GHz. The 200 MHz requirement is a result of assigning each of 45-50 beams to a separate 4 MHz channel (concept 2 was based on a design not requiring aircraft transmission synchronization by the surveillance system; however, to retain system flexibility, 1 MHz of satellite-to-aricraft spectrum is reserved for such functions as possible synchronization of aircraft transmission and system integrity messages).

This concept would also require all the spectrum needed for the Automatic Dependent Surveillance Concept of Section 7.1, except that the Uplink Space Digital Communications requirements would be reduced from 4.8 MHz to about 2.5 MHz due to a decreased rate of automatic dependent surveillance position reporting. Table 7.2 below summarizes the L-band spectrum needs for this concept.

While the required number of CAT I MLS facilities may be reduced, the channel frequencies of 5031-5091 MHz will be retained to support CAT II and CAT III landing facilities. The DME function, which uses frequencies between 960 and 1215 MHz may eventually be replaced by use of GPS measurements.

7.2.7 Alternative Technique for Concept 2

The task group chose Concept 2 because of the high level of independence it provides for the surveillance function. That is, the system independently provides 3-dimensional surveillance without any aircraft-derived altimeter input. The group also considered another concept that uses synchronized ranging. The alternate concept provides considerably less independence of measurements, but has merit. Used in conjunction with the automatic dependent surveillance system of Concept 1, it could serve to crosscheck the navigation-derived measurements, and provides a level of independent measurement capability.

This alternate concept is based on a tone-ranging scheme to establish spectrum requirements, although other schemes such as spread-spectrum techniques could also be used. In this scheme, position measurements are derived from two commercial geostationary satellites and the airborne altimeter. The geometry provided by a third geostationary satellite would not support the accuracy requirements of surveillance. The single most objectionable feature of this scheme is that without an onboard measurement of altitude, which requires an encoding altimeter on every participating aircraft, there will not be a full knowledge of the aircraft's position. Furthermore, an error in reported altitude translates into a comparable error in position.

This scheme has several attractive features:

- Assuming the service would become available within a decade, the effectiveness of the scheme could be tested without a large capital investment on the part of the government.

[illegible] FEB 5 1965

[illegible] SPECTRUM REQUIRED FOR OPERATIONAL CONTROL

Introduction

Operational control communications are conducted in the radio frequency spectrum allocated by the International Telecommunication Union (ITU) exclusively to the aeronautical mobile (R) service. Today, operational control communications are conducted at VHF and HF and in the future, will be accommodated in higher portions of the radio frequency spectrum such as the exclusive aeronautical mobile satellite (R) bands between 1535 and 1660.5 MHz (commonly called "L-Band"). In the not too distant future, it is envisaged that this band will be used for both terrestrial and satellite applications [illegible] for domestic use and via satellite for use over oceanic and remote areas. This paper summarizes studies which show at least 5.6 MHz spectrum in this band will be needed to adequately satisfy the requirements on a world-wide basis by the year 2010.

Background

The ICAO [illegible] Definitions, defines operational control as follows:

> [illegible] control. The exercise of authority over the [illegible] continuation, diversion or termination of a flight in the interest of the safety of the aircraft, and the regularity and efficiency of a flight.

[illegible] states: "An operator or his designated [illegible] shall have responsibility for operational control."

The requirement of operational control has come into prominence due to the development of civil aviation accompanied by an increase in the [illegible] of commercial aircraft able to operate over longer distances, at greater heights and in adverse weather conditions, by a considerably increased traffic density and by [illegible] competition between the various aircraft operating [illegible] civil air transport operations, [illegible] was responsible for operational planning and [illegible] as was possible through his local [illegible] acting in consultation [illegible] meteorological [illegible] imposed on the aircraft by [illegible] more than moderate [illegible] a large degree on [illegible] and [illegible] to restricted [illegible] to air navigation, [illegible] was limited and much was [illegible] command to commence, [illegible] hand the volume

Table 8.6

SUMMARY — SPECTRUM REQUIREMENT FOR MOST DEMANDING CONCEPT

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
*Space Communications (including automatic dependent surveillance reporting once every 10 seconds)			
Digital	3.3 MHz	2.5 MHz	
Voice	1.2 MHz	1.2 MHz	
**Terrestrial (Ground-to-Air, Non-Satellite Voice & Data (including 1 MHz buffer on downlink)	2.4 MHz	1.65 MHz	
*Space Communications Adjacent geographic area Services (where frequency reuse is not possible)	1.0 MHz	1.0 MHZ	
***Space Cooperative Independent Surveillance	1.0 MHz	4.0 MHz	
Space Radar (noncooperative surveillance)			20 MHz****
Space Communications (Operational Control)	5.6 MHz	5.6 MHz	
	14.5 MHz	15.95 MHz	20 MHz

*These frequencies can be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 are fully satisfied.

**Not sharable

***Not sharable if space-based system similar to Mode S is chosen. Possibly not sharable if synchronized, range-based system is used.

****Spectrum for this function expected to utilize a radionavigation satellite band between 1585 and 1610 MHz.

Table 3.4

FOR CONCEPT 3 -- ATC FUNCTIONS

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
As for Concept 2	8.9 MHz	10.35 MHz	
plus			
Space Radar (noncooperative surveillance)			20 MHz*
	8.9 MHz	10.35 MHz	20 MHZ

*Spectrum for this function expected to utilize a radionavigation satellite band between 1585 and 1610 MHz.

Table 3.5

SPECTRUM REQUIREMENT FOR OPERATIONAL CONTROL FUNCTIONS -- ALL CONCEPTS

(provided by ARINC/ATA on behalf of scheduled airlines)

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
Space Communications (Operational Control)	5.6 MHz	5.6 MHz	

Table 8.3

FOR CONCEPT 2 (A or B) -- ATC FUNCTIONS

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
*Space Communications (including automatic dependent surveillance reporting once every 10 seconds)			
Digital	3.3 MHz	2.5 MHz	
Voice	1.2 MHz	1.2 MHz	
**Terrestrial (Ground-to-Air) Non-Satellite Voice & Data (including 1 MHz buffer on downlink)	2.4 MHz	1.65 MHz	
*Space Communications Adjacent geographic area Services (where frequency reuse is not possible)	1.0 MHz	1.0 MHZ	
**Space Cooperative Independent Surveillance (System similar to Mode S surveillance function, with independent altitude check)	1.0 MHz	4.0 MHz	
or			
***Space Cooperative Independent Surveillance (Synchronized, range-based surveillance requiring aircraft altimeter data)	1.0 MHz	4.0 MHz	
	8.9 MHz	10.35 MHz	

*These frequencies can be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 are fully satisfied.

**Not sharable

***Possibly not sharable

Table 8.2

FOR CONCEPT 1 -- ATC FUNCTIONS

	DOWNLINK Paired L-Band	UPLINK Paired L-Band	OTHER BANDS
*Space Communications (including automatic dependent surveillance reporting)			
Digital	3.3 MHz	4.8 MHz	
Voice	1.2 MHz	1.2 MHz	
**Terrestrial (Ground-to-Air) Non-Satellite Voice & Data (including 1 MHz buffer on downlink)	2.4 MHz	1.65 MHz	
*Space Communications Adjacent geographic area Services (where frequency reuse is not possible)	1.0 MHz	1.0 MHZ	
	7.9 MHz	8.65 MHz	

*These frequencies can be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 are fully satisfied.

**Not sharable

It was noted above that a practical design for a satellite communications service requires consideration of frequency, time, and coding multiplexing schemes. Provision must also be made to permit cost- and spectrum-efficient introduction of the services, growth in service demand, and possibly cyclical changes in demand, as well as considerations of avionics cost. For the purpose of this study, certain assumptions were made about such factors, but no complete design was performed which would establish optimal channeling, specific frequency reuse, required oscillator stability and Doppler shift accommodation, modulation and coding formats, inefficiencies introduced to permit simple system acquisition and preclude interference, etc. Such specific designs will have an impact on final spectrum requirements.

Practical designs could result in a need for more spectrum than has been identified here, but the group felt that the rapid technical evolution of satellite system designs, along with the prospect for a gradual introduction of the services, makes the assumptions reasonable for now

The summary tables below do not include the L-band spectrum utilized by the GPS. While the SPS capability presently promised to the civil community takes only about 2 MHz of spectrum centered at 1575.42 MHz; the total GPS system, with its dual frequency precision ranging capability, utilizes a total of slightly over 40 MHz (±10.23 MHz centered at 1575.42 MHz and at 1227.6 MHz). (In addition, the GPS employs approximately 4 MHz for satellite control).

8.6 Spectrum Requirements for Space-Based Cooperative Independent Surveillance

The spectrum requirements for a space-based cooperative independent surveillance function (Section 7.2) is estimated to be 4 MHz for the uplink and 1 MHz for the downlink. This bandwidth is estimated to be needed to handle a 50,000 peak instantaneous aircraft count with a peak aircraft position update rate of once per second in terminal areas and a rate of once each 4 seconds for en route airspace. This function is assumed to be implemented in the paired L-band segments (i.e., 1545-1559 MHz and 1646.5-1660.5 MHz), but might also be considered for implementation elsewhere in the aeronautical mobile satellite (R) band segments.

An alternate space-based cooperative independent surveillance system concept based on using two-way ranging with geostationary satellite and using aircraft-derived altitude inputs is estimated to require a similar amount of spectrum.

8.7 Space Radar

A total of 20 MHz of frequency spectrum has been estimated to be needed to implement a space-based non-cooperative independent surveillance function. Consideration should be given for reserving such spectrum in a suitable band for this function. The spectrum for this function would be expected to come from a radionavigation satellite band between 1585 MHz and 1610 MHz.

8.8 Summary of Estimated L-Band Spectrum Requirements

The following tables present summaries of the L-band spectrum requirements estimated to be needed in the 2010 time period for the concepts considered for the identified functions, and considering various assumptions regarding future traffic, information flow, satellite system design, and system efficiency. Tables 8.5 and 8.6 also consider the spectrum requirements for operational control functions estimated and provided by ARINC/ATA.

requirement for voice is assumed to be 1.2 MHz for each direction, the same as for the satellite service. The bandwidth requirements for data are derived from Table 6-2, but using a peak airborne count of 1500 assuming the busiest terminal area, as derived in Section 5.4. This resulted in data communication spectrum requirements of 0.2 MHz and 0.45 MHz for the ground-to-aircraft and aircraft-to-ground directions respectively. Because of the uncertainty of this concept at this time, the spectrum requirement for satellite services was not reduced as a result of adding L-band terrestrial ground/air service.

Aircraft are expected to receive voice and data communications from both satellite-based and terrestrial-based services in the same 1545-1559 MHz band. There would be considerable disparity in received power in the aircraft from these two services. Degradation is likely to occur in receiving satellite communications onboard aircraft from adjacent terrestrial-based transmissions. Therefore, while no studies have been carried out to investigate this concern, a buffer of 1 MHz has been allocated to separate these satellite-based and terrestrial-based services.

8.4 Operational and Administrative Communications Spectrum Requirements

The bandwidth required to permit aircraft to communicate with corporate facilities has been estimated by ARINC to be 5.6 MHz (see Appendix A). This estimate is based on a baseband/RF translation improvement of more than two-to-one over existing voice and data services. No additional frequency reuse over that presently used is assumed.

8.5 Spectrum Requirements for Areas Adjacent to High-Traffic Areas

In order to provide a continuity of service to/from geographic areas adjacent to high-traffic areas where frequency reuse is likely not to be employed, an additional 1 MHz of spectrum is estimated to be required. It is assumed that such spectrum would be sufficient to provide voice and data communications to the far lower number of expected users in these areas (see Section 5.7).

The result is a digital data requirement of 4.8 MHz and 3.3 MHz for the uplink (i.e., aircraft-to-satellite) and downlink (i.e., satellite-to-aircraft) respectively.

TABLE 8-1

SUMMARY OF DIGITAL DATA COMMUNICATIONS

	MBPS	UTILIZATION FACTOR	SPECTRUM* (MHz)
o Aircraft to Ground			
- Terminal	4.5	0.7	1.6
- En Route	9.0	0.7	3.2
			4.8
o Ground to Aircraft			
- Terminal	2.0	0.7	0.7
- En Route	7.3	0.7	2.6
			3.3

*Assumes 4:1 Reuse

8.2 Satellite System Voice Spectrum Requirements

The spectrum requirement for satellite-based voice communications was derived from the existing service in the 118-136 MHz VHF band, which utilizes a channel spacings as low as 25 KHz. It has been assumed that voice channels could be reduced to 12.5 KHz using modern oscillator technology. In addition, it was assumed that the demand for voice channels can be reduced in half by utilizing data channels for the majority of the communications. As a result, a voice bandwidth of 1.2 MHz has been estimated to be adequate for both the uplink and the downlink. Since the present implementation at VHF already uses extensive frequency reuse, no further frequency reuse was included.

8.3 Terrestrial System Voice and Data Spectrum Requirements

A [illegible] terrestrial voice and data capability is assumed for use in terminal areas. This service may serve as a primary terminal service or as a back-up service to the satellite communication service. The bandwidth

8. Spectrum Requirements

The communication bandwidth requirements to support the three concepts described in Section 7 to service a high-traffic region are summarized in this section. Consideration is also given for the possible spectrum needed for lower traffic density adjacent areas. The bandwidth requirements developed in this section are for the aircraft-to-satellite (i.e., uplink) and satellite-to-aircraft (i.e., downlink) communications. The bandwidth requirements for the earth station-satellite links are not addressed.

The digital data flow requirements estimated in Section 6 have been used as a basis for estimating the frequency spectrum for digital data communications. The estimates of frequency spectrum needed for voice services have been based upon a consideration of present voice services and bandwidth utilization.

8.1 Satellite System Digital Data Spectrum Requirements

The satellite system digital data communication spectrum requirements to support Concept 1 are presented in Table 8-1. These estimates are based upon the information flow estimates presented in Section 6. The basic MBPS rates from Section 6 include allowances for protocols and Rate 1/2 error correction coding. These data rates have been translated into radio frequency (RF) spectrum bandwidths under the following assumptions:

(1) The translation from baseband to RF, and vice versa, can be implemented on a 1 BPS to 1 Hz ratio.

(2) A 70 percent channel utilization efficiency factor is assumed (e.g., to prevent garbling or interference).

(3) A four-to-one system frequency reuse factor is assumed.*

* See Appendix B for discussion on frequency reuse.

Table 7.2

L-Band Spectrum Requirements for Concept 2[1]

Function	Downlink 1545-1559 MHz	Uplink 1646.5-1660.5 MHz
Space Digital Comm.	3.3	2.5
Space Voice Comm.	1.2	1.2
Terrestial Voice and Data (including a 1 MHz buffer in the downlink).	2.4	1.65
Space Coop. Ind. Serv	1.0	4.0
Adjacent Geographic Areas	1.0	1.0
	8.9 MHz[2, 4]	10.35 MHz[3, 4]

Notes:

1. The L-band spectrum for GPS is not included in this table (see Section 8).

2. 5.5 MHz of this total could be included in a shared service (6.5 MHz could be included in a shared service if an Alternative 2 type concept is considered).

3. 4.7 MHz of this total could be included in a shared service (8.7 MHz could be included in a shared service if an Alternative 2 type concept is considered.

4. The portions of spectrum from these totals that could be considered for a shared service (see Notes 2 and 3 above) could be shared with a secondary land mobile service which is implemented in such a manner as to assure that the sharing conditions of Section 4.4 are fully satisfied.

Synthetic aperture techniques, whereby the radar images taken at periodic intervals from a moving satellite are combined, offer a means of obtaining the necessary resolution in one dimension (along the line of satellite motion). However, there appears to be no means of synthetically achieving the same resolution in the lateral direction at the same time.

7.3.2 Conclusions

The size and complexity of the equipment is beyond the capability now being considered in the civil sector. A 20 MHz requirement for this system function is a minimum estimate. While it is very early to recommend specific spectrum to be reserved for this application, a possible location would be in the 1585 to 1610 MHz band.

7.2.8 Spectral Implications of the Alternate Concept

The spectral needs for the surveillance function are assumed the same as for primary Concept 2, or about 4 MHz band in the 1646.5-1660.5 MHz band and about 1 MHz in the 1545-1559 MHz band. The spectrum needs for the other functions are also the same as those of the primary Concept 2 (see Table 7.2 below).

7.3 Noncooperative Surveillance Concept - Concept 3

To perform the service with a single space-based radar would imply a geostationary satellite of immense proportions, far beyond the current state of the art. For example, to scale the 50-foot radar to provide the same signal at geostationary altitude (25,000 miles) would require an antenna with a diameter of 150 miles (not to mention the problem of maintaining surface tolerances of a few inches over the span).

A better approach would be to forsake the notion of making angular measurements, and limit the radar to measuring range, which is not significantly affected by increasing the distance to the aircraft. In this concept, several radars would be used simultaneously in a triangulation scheme. The antenna diameter would then be chosen to provide one aircraft at a time in a beam most of the time.

If such an option were pursued, techniques would have to be available to generate large peak powers in space. Moving target indicator (MTI) techniques would be employed to reduce clutter from the earth, which would be much worse than that experienced by ground-based radars.

A phased array design would be mandatory, in order to provide the large number of beams required to cover the CONUS. At least 4 channels of 5 MHz each is estimated as a minimum to be required to allow different channels for of adjacent beams.

- Since it is assumed the satellites would be commercially operated, new channels could be leased as surveillance service was expanded, and as air traffic increased.

- The service could be readily provided outside the CONUS.

The scheme assumes about 1 MHz in the 1545-1560 MHz band for the interrogation message. This interrogation, which is continuous, establishes the timing of the aircraft return messages, and sets up conditions for accepting new aircraft onto the system.

In order to support the traffic density of an instantaneous airborne count of 50,000 and provide position reports every second in high-density terminal areas (once every four seconds in low-density areas), approximately 1500 channels must be provided. This implies a total bandwidth of 15 MHz in the aircraft-to-satellite direction. Assuming a frequency reuse factor of 4:1, approximately 4 MHz would be required to support a system of this type. It is estimated that approximately 1 MHz wouldbe needed for the satellite-to-aircraft direction.

The navigation and communications systems would be the same as those of the primary Concept 2, with similar data traffic loadings.

The surveillance system, as pointed out above, would not provide a crosscheck on aircraft altimeter that occurs with the primary Concept 2, but would depend on the aircraft altimeter to obtain positional data.

The collision avoidance function could not make use of either the navigation or surveillance signals. Thus, collision avoidance would have to be accomplished in a totally new manner. (There is the possibility of timing the reply of the airborne L-band transponders to GPS, rather than to the satellite-to-aircraft signal. If this were done, other aircraft could obtain the collision avoidance function by performing ranging on the other aircraft's responses to interrogations.)

of air traffic was much less than it is today, and the air traffic controller experienced little difficulty in maintaining surveillance over aircraft leaving or approaching the aerodrome for which he was responsible. It was therefore possible to give each aircraft individual attention within the limited resources at his disposal and also to inform the operator or his representative of aircraft movements. This method of operation had many drawbacks. It was uncertain and, in many cases, resulted in delays which were costly to the operator and inconvenient to the passengers. It became increasingly obvious that last minute decisions were to be avoided if the operation was to provide reasonable services and economy.

As a result of the demand for better services, aeronautical facilities improved and operators sought means of providing better planning for the purpose of increasing regularity of service and of improving the quality of information exchanged between departments within their organization. In many cases, it was found that it was not adequate to await the decisions of the pilot in command concerning the feasibility of operations. Also, while enroute, the pilot in command did not always possess sufficient information in the cockpit to assess changing circumstances. This situation became further complicated by the advent of faster and more complex aircraft and accompanying requirements for greater pilot attention to the flying technique.

As the frequency and complexity of operations increased, so did the factors that had to be considered. Eventually, it became either impracticable or impossible for the pilot in command to assess alone all the various factors requiring consideration prior to and during a flight operation. This resulted in advice being given to the pilot by qualified personnel on the ground. This system of advice increased the efficiency of flight operations by relieving the pilot of a considerable burden and allowing consultation and decision on critical issues with personnel who had available to them more factors bearing on an operation and who were able to keep under constant review and analyze a whole network of operations of which any particular flight was only a part. Thus, teamwork between the pilot, who is ultimately responsible for the safety of the aircraft, and personnel on the ground having a broader view of the operation, contributed considerably to the safety and regularity of aircraft operations. The advent of improved air-ground communications allowed ground personnel to relay additional information received after the aircraft was airborne, thereby increasing the value of in-flight assistance.

The situation throughout the world, therefore, has developed into a concept of shared advice and responsibilities between the pilot and ground personnel - to the extent of cooperation depending upon many factors such as the size of the operation, the facilities available and the system of operation established by the aircraft operating agency. The aircraft operating agency, no matter what its size, is primarily responsible for conducting his

operations with safety and efficiency. The corollary of the operator's responsibility is his inherent right to conduct his operations in a manner which he deems best so long as he conforms to the laws and regulations of the State of Registry of his aircraft and those of other States in which he operates. Factors affecting the exercise of responsibility by the aircraft operating agency include utilization of aircraft and flight crews, complexity and density of flight operations proper passenger accommodations and protection, necessity for advance planning, operational maturity, geographical scope of operations, unlawful interference with flight operations, in-flight maintenance and medical advice.

Today, aeronautical operational control communications are considered aeronautical mobile (R) service communications related to regularity of flight. These non-public communications are prerequisite to the discharge by aircraft operating agencies of their obligation to exercise authority over the initiation, continuation, diversion or termination of flight. Aviation agencies regard the term 'regularity of flight' in the above context as entirely acceptable and useful to distinguish this type of communications from 'safety of flight' communications, in the context of air traffic control. In this context the term 'flight regularity' looks upon aeronautical operational control as non-public communications related to the safe, efficient and economic operation of aircraft. However, aviation has evolved highly complex and time critical operations in response to the traveling public's demand for more comprehensive services to support their air transportation. The associated requirement for communications is for a service capable of providing direct voice and data communications between designated officials of the aircraft operating agency and its aircraft to best fulfill these service needs.

The situation that has now emerged seems quite clear. Aeronautical operational control is recognized by the International Civil Aviation Organization (ICAO) and regional requirements state that means should be provided to permit aircraft operating agencies to exercise such control. Most Administrations have provided or permitted such means to the extent possible and, in fact accommodate provisions for operational control in their national regulations.

Sizing Spectrum Needs

The significance of operational control communications is reflected by the consistent growth experienced over the past years. In some areas of the world today a major portion of the available VHF channels is required to meet the needs of aircraft operating agencies for operational control or "Company Communications". These same areas are faced with imminent saturation in both operational control and air traffic control channels. This growth is illustrated in Figure 1 which shows the number of operational control frequency assignments in the United States in recent years.

Introduction of digital data communications has greatly expanded the effectiveness of operational control communications. Figure 2 shows the early growth in use of the VHF ACARS to the present level of almost 15 million messages per year within the United States. The same figure shows the growth in needs estimated by users. A compatible network began operation in Australia during 1984 and will be expanded throughout the Asia corridor toward Japan during 1985.

It should be noted that the introduction of digital data on VHF has supplemented, but not replaced, voice communications. This is clearly shown in comparing Figures 1 and 2.

The projected growth in aircraft movements is shown in Figure 3. The associated communications needed to improve safety, energy conservation and operating efficiency are summarized in Figures 4, 5 and 6 to reflect annual increases of 4, 5, and 6 percent in aircraft movements. The new trend toward the introduction of smaller aircraft, including the use of two-engine aircraft in oceanic services, make these estimates conservative, indeed. The spectrum needs shown in these tables are based upon total worldwide operations, categorized by geographical area. The projected needs are stated in radio frequency bandwidth. The assumptions include a frequency reuse factor at least equivalent to that achieved today in the areonautical VHF band and a continued improvement in the ratio of signal base band to radio frequency occupancy. This is optimistic in view of the fact that the introduction of satellite communications will impose limits on frequency reuse.

The data in Figures 5A and 5B show a conservative 5 percent per year growth rate in aircraft movements anticipated in the years 1995 and 2010 as compared to 1984. The data show the aviation spectrum sizing will be dictated by the traditionally high density areas of operation found in North America and Europe. The operation of large transport aircraft in North America will require at least 4.1 MHz for operational control. While the growth impact of General Aviation is less certain, and their demands will center upon Air Traffic Control, the conservative scaling factors used in this study place their needs for operational control and company communications at 1.5 MHz for voice and data in the year 2010. The combined needs will be 5.6 MHz.

The sensitivity of these projected needs to variations in growth is indicated by the data in Figures 4A/4B and 6A/6B. The results presented in Figure 4B show a more conservative annual growth of 4 percent per year which demonstrates the need for at least 4.4 MHz by the year 2010. A growth rate of 6 percent, only 0.5 percent above that projected by ICAO, demonstrates the need for 7.1 MHz by the year 2010 as shown in Figure 6B. Thus, the intermediate value of 5.6 MHz for the projected operational control communications, with allowances for frequency reuse, appears properly qualified.

Conclusions

The ICAO Future Air Navigation Systems (FANS) and RTCA SC-155 special committees are in the midst of applying the "system design" concepts defined by ICAO to meeting future aeronautical communication needs. The report of ICAO's FANS/1 recognizes the need for common airborne equipment to serve Air Traffic Control, Aeronautical Operational Control and Public Correspondence functions. As an example of the benefits, today the user's mandatory carriage includes 2 or 3 VHF, 2 HF and the prospects of 2 satellite plus 1 Public Correspondence suites of airborne equipment; a total of 7 or 8 separate systems. Future carriage of, say, four fundamentally identical systems would significantly increase the reliability of each function and the flexibility to meet peak communication demands. Such an approach would save significant energy and increase aircraft productivity over the useful life of the new systems. Incentives such as these are essential to future progress.

The combined future worldwide need for aeronautical communication spectrum, even with optimistic estimates of system design and application technology appears to exceed the capacity offered by the existing Aeronautical Mobile Satellite (R) allocations in the present ITU Radio Regulations. A cursory test of this conclusion is to compare the projected needs with present actual usage. The projected 5.6 MHz is less than double that of the 3.2 MHz in use for these purposes today.

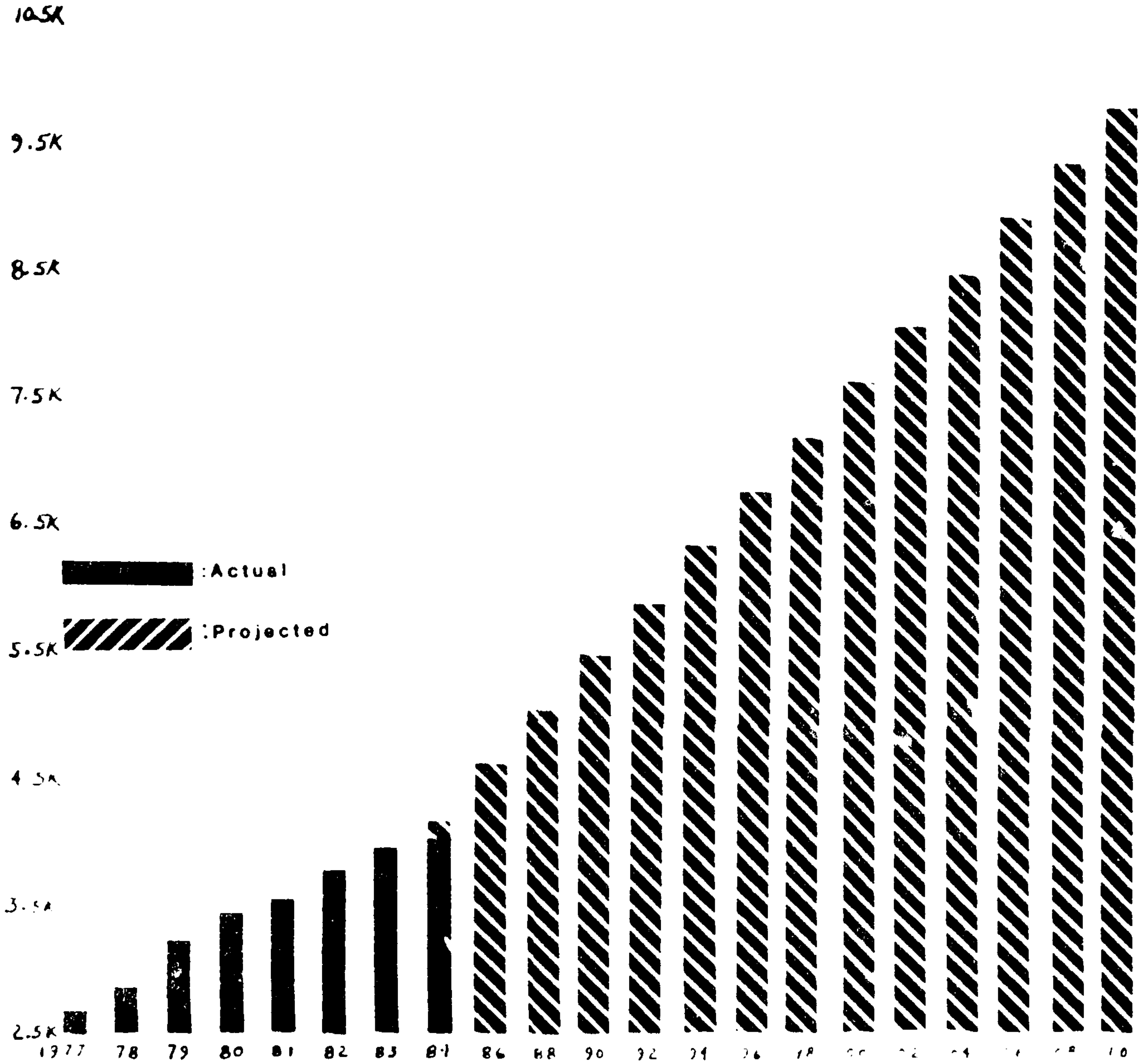

Figure 1. Assignments in the VHF Operational [illegible] Band, 1977-2010

ACARS USER MESSAGE TREND (IN MILLIONS)

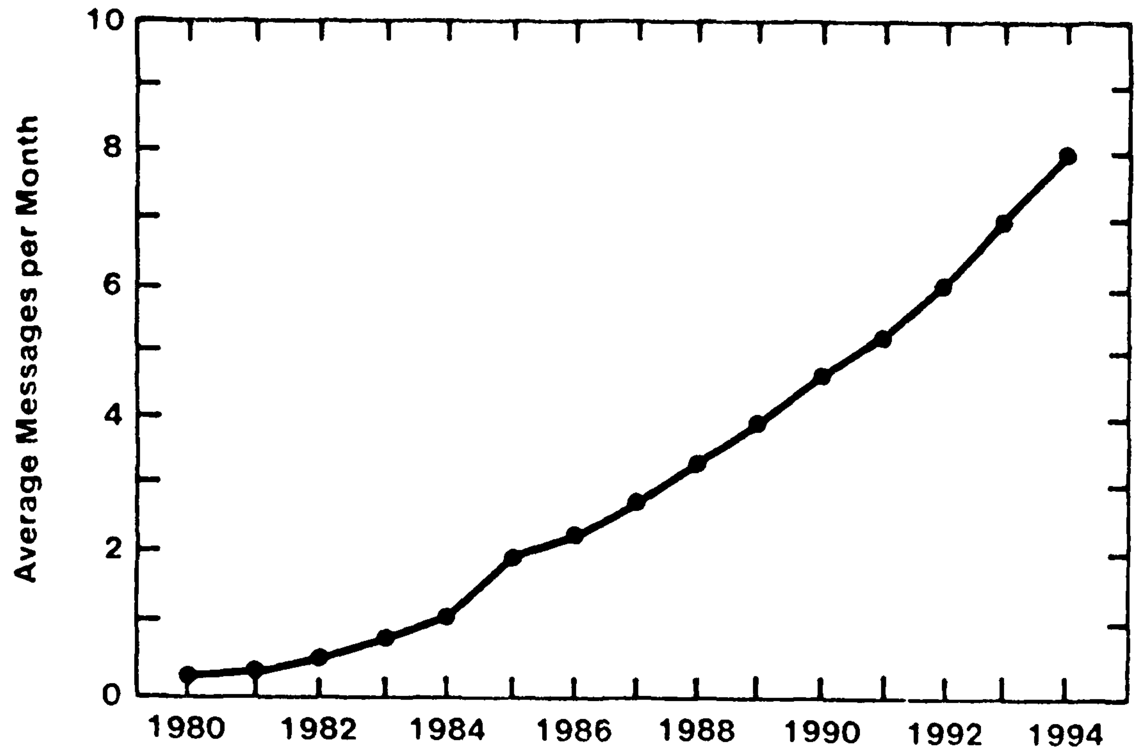

Figure 2

LBAND STUDY - AIRCRAFT POPULATIONS (LBACFT) 1/10/85

PRIMARY DATA INPUTS ----- YEAR - - >	1984	- - - - 1995	- - - - -		- - - - 2010	- - - - -	
GROWTH RATE (PERCENT PER YEAR)		4%	5%	6%	4%	5%	6%
AREA ACTIVITY LEVELS	PIAC	PIPC	PIAC	PIAC	PIAC	PIAC	PIAC
1. AFRICA	87	129	141	156	232	295	373
2. ASIA	300	444	486	537	801	1,017	1,287
3. CARRIBBEAN	120	178	194	215	320	407	515
4. EUPOPE	600	888	972	1,074	1,602	2,034	2,574
5. INDIAN OCEAN	38	56	62	68	101	129	163
6. MID-EAST	60	89	97	107	160	203	257
7. NO. AMERICA-TRANSPORT	1400	2,072	2,268	2,506	3,738	4,746	6,006
8. NO. AMERICA-GEN. AVIATION (19k*.6)	11400	16,872	18,468	20,406	30,438	38,646	48,906
9. NO. ATLANTIC	385	570	624	689	1,028	1,305	1,652
10. PACIFIC	177	262	287	317	473	600	759
11. SO. AMERICA	133	197	215	238	355	451	571
12. SO. ATLANTIC	57	84	92	102	152	193	245
TOTALS	14,757	21,840	23,906	26,415	39,401	50,026	63,308

Figure 3. Projected Peak Instantaneous Aircraft Count (PIAC)

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	ATC			AOC			PUBLIC CORRESPONDENCE			TOTAL SPECTM
	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-MB	(KHZ)
1 AFRICA	150	40	44	100	30	29	4,130	15,020	5,586	19,470
2 ASIA	500	120	147	320	80	93	14,210	51,800	19,253	67,030
3 CARRIBBEAN	200	50	59	130	30	38	5,690	41,300	12,641	47,400
4 EUROPE	990	230	291	640	140	186	28,420	310,800	88,234	341,220
5 INDIAN OCEAN	70	20	20	40	20	12	1,800	6,580	2,441	8,530
6 MID-EAST	100	30	29	70	20	20	2,850	10,330	3,845	13,400
7 N. AMERICA-TRNSP	2,300	520	676	1,480	320	430	66,310	725,200	205,877	7.9613e5
8 N. AMERICA-GEN A	9,370	850	2,451	600	60	156	54,000	1.036e6	26,027	1.1009e6
9 N. ATLANTIC	640	150	188	410	90	119	18,240	119,700	37,480	139,230
10 PACIFIC OCEAN	300	70	88	190	50	55	8,390	30,610	11,369	39,610
11 S. AMERICA	220	50	65	140	30	41	6,300	22,910	8,519	29,650
12 S. ATLANTIC	100	30	29	60	20	18	2,700	9,770	3,638	12,680
TOTALS	14,940	2,160	4,086	4,180	890	1,195	213,040	2.3800e6	4.2491e5	2.6152e6

Figure 4A. 1995 Projected Spectrum Requirements (Aircraft Movement Growth - 4%)

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	ATC			AOC			PUBLIC CORRESPONDENCE			TOTAL SPECTM
	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-MB	(KHZ)
1 AFRICA	260	60	76	170	50	49	7,440	27,090	.0,072	35,070
2 ASIA	890	210	262	570	140	166	25,640	93,450	34,735	120,900
3 CARRIBBEAN	360	90	106	230	60	67	10,260	74,500	22,802	85,500
4 EUROPE	1,780	410	523	1,140	260	331	51,270	560,700	159,178	615,560
5 INDIAN OCEAN	120	30	35	80	30	23	3,250	11,860	4,404	15,370
6 MID-EAST	180	50	53	120	30	35	5,130	18,640	6,932	24,150
7 N. AMERICA-TRNSP	4,150	940	1,220	2,660	570	773	119,620	1.3083e6	371,410	1.4362e6
8 N. AMERICA-GEN A	16,900	1,530	4,421	1,090	110	284	9.741e4	1.869e6	46,950	1.9860e6
9 N. ATLANTIC	1,150	260	338	730	170	212	32,900	215,930	67,614	251,140
10 PACIFIC OCEAN	530	120	156	340	80	99	15,130	55,200	20,508	71,400
11 S. AMERICA	400	90	117	260	60	75	11,370	41,320	15,371	53,500
12 S. ATLANTIC	170	40	50	110	30	33	4,880	17,620	6,568	22,850
TOTALS	26,890	3,830	7,357	7,500	1,590	2,146	3.843e5	4.2936e6	7.6654e5	4.7177e6

Figure 4B. 2010 Projected Spectrum Requirements (Aircraft Movement Growth - 4%)

CLN2IA95L: 1/10/85 1995 SUMMARY COMMUNICATIONS

	ATC			AOC			PUBLIC CORRESPONDENCE			TOTAL SPECTM
	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-MB	(KHZ)
1 AFRICA	160	40	47	100	30	29	4,520	16,450	6,114	21,300
2 ASIA	540	130	159	350	80	101	15,560	56,700	21,077	73,360
3 CARRIBBEAN	220	50	64	140	30	41	6.230	45,200	13,837	51,870
4 EUROPE	1,080	250	318	700	150	203	31,110	340,200	96,581	373,490
5 INDIAN OCEAN	70	20	20	50	20	14	1,970	7,200	2,671	9,330
6 MID-EAST	110	30	32	70	20	20	3,120	11.310	4,209	14,660
7 N. AMERICA-TRNSP	2,520	570	741	1,620	350	470	72,580	793,800	225,350	8.7144e5
8 N. AMERICA-GEN A	10,250	930	2,682	660	60	172	5.91e4	1.134e6	28,485	1.205e6
9 N. ATLANTIC	700	160	205	450	110	130	19,960	131,020	41,023	152,400
10 PACIFIC OCEAN	320	80	94	210	50	61	9,180	33,500	12,443	43,340
11 S. AMERICA	240	60	71	160	50	46	6,900	25,080	9,327	32,490
12 S. ATLANTIC	110	30	32	70	20	21	2,960	10,690	3,985	13,880
TOTALS	16,320	2,350	4,465	4,580	970	1,309	233,190	2.6052e6	465,103	2.8626e6

Figure 5A. 1995 Projected Spectrum Requirements (Aircraft Movement growth - 5%)

(LN2IA1?2) 1/10/85 2010 S U M M A R Y C O M M U N I C A T I O N S

	ATC			AOC			PUBLIC CORRESPONDENCE			TOTAL SPECTM
	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-MB	(KHZ)
1 AFRICA	330	80	97	210	50	61	9,440	34,400	12,785	44,510
2 ASIA	1,130	260	332	730	170	212	32,550	118,650	44,100	153,490
3 CARRIBBEAN	460	110	135	290	80	84	13,020	94,590	28,948	108,550
4 EUROPE	2,260	510	664	1,450	320	421	65,090	711,900	202,099	781,530
5 INDIAN OCEAN	150	40	44	100	30	29	4,130	15,050	5,593	19,500
6 MID-EAST	230	60	67	150	50	43	6,510	23,660	8,799	30,660
7 N. AMERICA-TRNSP	5,270	1,190	1,550	3,370	720	980	151,880	1.6611e6	471,566	1.8235e6
8 N. AMERICA-GEN A	21,450	1,940	5,612	1,380	120	359	123,670	2.373e6	59,607	2.5216e6
9 N. ATLANTIC	1,450	330	426	930	210	270	41,770	274,160	85,846	318,850
10 PACIFIC OCEAN	670	150	197	430	90	125	19,210	70,090	26.038	90,640
11 S. AMERICA	510	120	149	330	80	95	14,430	52,450	19,514	67,920
12 S. ATLANTIC	220	50	64	140	30	42	6,190	22,370	8,336	29,[illegible]00
TOTALS	34,130	4,840	9,338	9,510	1,950	2,721	487,890	5.4514e6	973,232	5.9897e6

Figure 5B. 2010 Projected Spectrum Requirements (Aircraft Movement Growth - 5%)

(LN2IA951) 1/10/85 1995 S U M M A R Y C O M M U N I C A T I O N S

	ATC			AOC			PUBLIC CORRESPONDENCE			TOTAL SPECTM
	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-MB	(KHZ)
1 AFRICA	180	40	53	120	30	34	4,990	18,170	6,753	23,530
2 ASIA	600	140	176	390	90	113	17,190	62,650	23,287	81,060
3 CARRIBBEAN	240	60	70	160	50	46	6,880	49,950	15,288	57,340
4 EUROPE	1,200	270	352	770	170	223	34,370	375,900	106,714	412,680
5 INDIAN OCEAN	80	20	23	50	20	14	2,180	7,950	2,953	10,300
6 MID-EAST	120	30	35	80	30	23	3,440	12,500	4,648	16,200
7 N. AMERICA-TRNSP	2,790	630	820	1,780	390	517	80,200	877,100	249,000	1.6289e5
8 N. AMERICA-GEN A	11,330	1,030	2,964	730	80	190	65,300	1.253e6	31,473	1.3315e6
9 N. ATLANTIC	770	180	226	490	110	142	22,060	144,760	45,331	168,370
10 PACIFIC OCEAN	360	80	105	230	60	67	10,140	37,010	13,747	47,880
11 S. AMERICA	270	60	79	170	50	49	7,620	27,700	10,304	35,870
12 S. ATLANTIC	120	30	35	80	30	24	3,270	11,810	4,402	15,340
TOTALS	18,060	2,570	4,940	5,050	1,110	1,444	257,640	2.8785e6	513,900	3.1629e6

Figure 6A. 1995 Projected Spectrum Requirements (Aircraft Movement Growth - 6%)

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	ATC			ADC			PUBLIC CORRESPONDENCE			TOTAL SPECTM
	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-KBPS	VOICE-KHZ	DATA-KHZ	DAMA-MB	(KHZ)
1 AFRICA	420	100	123	270	60	78	11,950	43,530	16,181	56,330
2 ASIA	1,430	330	420	920	200	267	41,190	150,150	55,807	194,220
3 CARRIBBEAN	580	130	170	370	90	107	16,480	119,700	36,635	137,350
4 EUROPE	2,860	650	841	1,830	390	532	82,370	900,900	255,754	989,000
5 INDIAN OCEAN	190	50	55	120	30	35	5,220	19,060	7,075	24,670
6 MID-EAST	290	70	85	190	50	55	8,240	29,930	11,136	38,770
7 N. AMERICA-TRNSP	6,670	1,510	1,961	4,270	920	1,241	192,200	2.1021e6	596,760	2.3077e6
8 N. AMERICA-GEN A	27,150	2,450	7,103	1,740	150	453	1.565e5	3.003e6	75,430	3.1910e6
9 N. ATLANTIC	1,840	420	541	1,180	260	343	52,860	346,940	108,637	403,500
10 PACIFIC OCEAN	850	190	250	540	120	157	24,300	88,690	32,946	114,690
11 S. AMERICA	640	150	188	410	90	119	18,260	66,380	24,694	85,930
12 S. ATLANTIC	280	70	82	180	50	54	7,830	28,300	10,548	36,710
TOTALS	43,200	6,120	11,819	12,020	2,410	3,440	6.174e5	6.8987e6	1.2316e6	7.5798e6

Figure 6B. 2010 Projected Spectrum Requirements (Aircraft Movement Growth = 6%)

Appendix B
Consideration of Frequency Reuse

This study has considered a frequency reuse of four in its final determination of frequency spectrum needs for the year 2010. The net effect of this frequency reuse factor is that it is assumed that a multi-beam satellite system would be implemented such that only 1/4 the frequency spectrum would be needed relative to providing the same level of service with a single beam. What would such a frequency reuse factor imply in terms of the number of beams necessary to cover the continental U.S., and what would be the implications in terms of system service flexibility? The following example and discussion address these aspects.

Suppose, for example, that there was a need for a communications service totaling 16 MBPS (million bits per second) for the continental U.S., which translated into a need for 16 MHz of frequency spectrum (assuming a 1 BPS to 1 Hz translation relationship). Thus, a single satellite beam covering the U.S. using 16 MHz of spectrum could provide a 16 MBPS service. Considering a frequency reuse of four, a satellite beam configuration would be needed such that an equivalent service (of 16 MBPS of total data flow) could be provided with 4 MHz (i.e., 16 MHz divided by the frequency reuse factor).

If four beams could be configured such that they did not touch, but could cover the total area, then the frequency reuse factor of four could be satisfied by employing the same frequency in each beam, each providing 4 MBPS of data capacity:

$$\frac{16\ \text{MBPS}}{\text{Total Area}} = \left(\frac{4\ \text{MBPS}}{\cancel{\text{Beam}}}\right)\left(\frac{4\ \cancel{\text{Beams}}}{\text{Total Area}}\right)$$

However, there must be a continuous service. Therefore, the beams must overlap. Thus, adjacent beams cannot be assigned the same frequencies.

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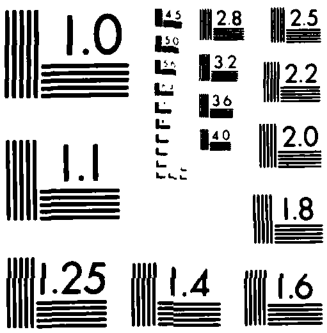
1.0
1.1
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1.6
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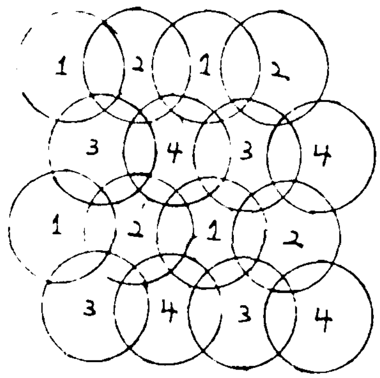
4.0

Consider that the 4 MHz of spectrum is divided into four-1 MHz parts, identified as 1, 2, 3, and 4. If each piece of spectrum is assigned to a beam providing 1 MBPS of capacity, and 16 such beams are configured to cover the continental U.S. such that: (1) they provide a continuous service through beam overlap, and (2) none of the overlapping beams contain the same frequencies; then a service nearly equal in capacity to the 16 MBPS single beam service could be provided (see figure below):

$$\frac{16 \text{ MBPS}}{\text{Total Area}} = \left(\frac{1 \text{ MBPS}}{\cancel{\text{Beam}}}\right)\left(\frac{16 \ \cancel{\text{Beams}}}{\text{Total Area}}\right)$$



This degree of multi-beam use, about 16 beams, is estimated to be needed to effect a basic frequency reuse of four.

System flexibility, however, is impacted by such a multi-beam system. In the single beam coverage case, all the capacity is available to be distributed for use in high traffic density areas and low traffic density areas as service demands require. However, the multi-beam case considered above satisfies the total service demand (i.e., 16 MBPS) given the assumption that the service demand is evenly distributed across the total geographic area. But, the continental U.S., probably like most areas, has various regions that have significantly higher service demands than others.

It may be very difficult to provide a significantly higher level of service to an area covered by a particular beam without: (a) implementing additional,

unique (i.e., different than the frequencies assigned to adjacent beams), frequencies to the beam, (2) sizing the system so that the peak demands of the most demanding area can be met, or (3) utilizing a larger degree of frequency reuse/number of beams, so that the system flexibility will be available to provide the total demand in a more adaptive manner analogous to the single beam case. Alternatives (1) and (2) above require the use of more frequency spectrum than implied by the frequency reuse factor (i.e., resulting in a net lower frequency reuse). Alternative (3) requires a more complex, multi-beam satellite system than implied by a total service demand (with no qualifications regarding service demand versus area needs) and a frequency reuse factor.

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